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PROGRAM SCHEDULING HANDBOOK.(U)

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This handbook is designed to help those responsible for developing and analyzing schedules of activities for programs in the defense system acquisition process. The aim is not to replace the more detailed and comprehensive treatments on scheduling topics that are available, but to give a condensed presentation of scheduling and analysis techniques and organize them in practical approach to solving typical program office scheduling problems. The examples used draw heavily on actual experience with acquisition programs at the Electronic Systems Division (ESD).

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FOREWORD

This handbook is part of an overall effort to establish and maintain a high level of expertise in our program business management operations. The ability to apply and analyze various scheduling techniques is an absolute necessity in doing our job of developing, producing, and delivering defense systems. We must relate schedules of a myriad of activities and participating organizations to accomplish this program management job successfully. Our intent here is to present some basics and practical approaches that will serve as an initial training aid and give a roadmap of procedures to integrate program office schedule information.

The key concepts here are the quantification and interrelation of the schedule characteristics of program tasks through a systems approach. This systems approach is simply an explicit structure that ties together the engineering, financial, logistics, contracts and other functional perspectives of a program. The ideas presented are workable, but we need more feedback on tailoring schedule systems to individual program circumstances and information needs. Submit your suggestions to:

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Colonel, USAF
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Chapter One

INTRODUCTION

Purpose

This handbook is designed to help those responsible for developing and analyzing schedules of activities for programs in the defense system acquisition process. Our aim is not to replace the more detailed and comprehensive treatments on scheduling topics that are available, but to give a condensed presentation of scheduling and analysis techniques and organize them in a practical approach to solving typical program office scheduling problems. The examples used will draw heavily on actual experience with acquisition programs at the Electronic Systems Division (ESD).

Background

The terms "scheduling" and "schedule performance" may seem a little artificial to those who have dealt with management problems. There is no real way to completely separate a set of tasks called scheduling and assign them to an individual along with the responsibility for schedule performance. Schedules are products of the planning process that lay out the expected time-frame of performance of activities needed to accomplish program objectives. Whether they occur "on-time" depends on how well each task is understood, in terms of technical specification and resources needed, and if the interrelationships with other tasks are known completely.

Scheduling is the process of obtaining the information on how long a job should take, relating it to the other jobs required to deliver the product, and laying out this data in a specific format to show when it must be done to fit all the constraints we know about. That sounds fairly simple, but historically, in defense and every other business, the track record is not good.

An analysis of our collective ability to schedule activities was presented as one of "Augustines Laws" by Norman R. Augustine in the Spring 1979 Defense Systems Management Review (page 55). Based on his own considerable experience in government and industry, he derives the "fantasy factor" that predicts any activity will take one-third more time than is currently estimated. Unfortunately, something close to that factor seems to crop up in many programs. We believe that the track record can be improved by establishing a clear set of groundrules for scheduling activities (style, approach, techniques) and applying them consistently.

Schedules of activities and events form one of the basic languages we use to communicate to get the job done. We "commit" to schedules by negotiating with our bosses; all plans and budgets are meaningless without the schedule relating the technical product and the cost. Especially in our business of developing and delivering defense systems, <u>when</u> the new capability can be put to use is of supreme importance.

We include scheduling as one of the six functions of Business Management in the sense that it is a subset of the tools needed to apply a disciplined approach to program management. Schedules are also a major part of our officially directed Program Baseline, in other words, our contract with Hq AFSC and Hq Air Force to deliver a specific product within cost and schedule constraints.

With the heavy emphasis on Program Baseline Management (AFSCR 550-18), the credibility of our schedule baseline is receiving increased attention. The technical (or product performance) baseline and the cost and schedule baselines are the three major quantities of the program management process. Each is but one dimension of a three dimensional whole. A change in any one of the dimensions means that the basic program has been modified and the other two will be changed as well. There is no way to describe a schedule problem without including the technical and cost impacts. The key is to define the relationships linking technical, cost, and schedule during the major planning efforts and as plans are updated.

Past performance in the area of scheduling has been criticized by the AFSC Inspector General (IG) and Program Management Assistance Group (PMAG) in reviews here at ESD and at the other AFSC product divisions. The recurring problems cited include:

1. Lack of a Program Master Schedule that integrates all major program activities, major decision points, and officially directed program milestone dates.

2. Schedules of major activities are not backed up by more detailed schedules of lower level activities.

3. Schedule uncertainty and risk analysis is minimal.

4. Schedule changes (contractions or extensions) are not analyzed to guage cost and technical impacts.

5. Contractor developed schedules are not given an independent analysis for credibility.

These problems exist for a number of reasons but we feel that the chief causes are: (1) a lack of staff guidance and followups, (2) a lack of working level knowledge of scheduling techniques and applications, and (3) an overall tendency to downplay the importance of schedule planning in favor of cost and technical effort. Our attempt here is a modest start to describe schedule characteristics as just one indispensible part of good planning and analysis. We hope to increase the working vocabulary of our program management language to allow straight-forward communication on such topics as network constraints, uncertainty calculations, and the quantification of risks and impacts of changes.

<u>Scope</u>

As stated earlier, we are not attempting to present a self-sufficient treatment of the topics covered. There are many good detailed sources for basic schedule techniques, and we assume that most readers have been exposed to some of them in previous technical and business oriented courses. (A list of references

will be given at the end of each chapter.) Each chapter will give a basic refresher on the techniques and then present some application cautions (strengths and weaknesses) and examples. This procedure will be used for the next four chapters covering: Gantt Charts, Milestone Schedules, Networks, and Line of Balance. Then, in Chapter 6, we will present a practical method for developing a Program Master Schedule based on a technique that allows easy modification to a large-scale network and lets us concentrate on the planning process and not the mechanics. Chapter 7 will expand the Master Schedule by looking at the need for Intermediate Schedules which break down major activities into the key component activities along with the identification of those responsible for completing them. Finally, Chapter 8 concentrates on techniques to quantify schedule uncertainty from the basic time estimates for each activity in a network. This last chapter draws from a number of sources and is a much more mathematical treatment than the rest of the handbook. It is intended for specialized applications such as Independent Schedule Assessments (AFSCR 800-35).

Chapter One References

1. Augustine, Norman R., "Augustines Laws and Major System Development Programs," Defense Systems Management Review, p. 50, Spring 1979, Defense Systems Management College, Ft. Belvoir, VA.

2. AFSCR 550-18, Program Baseline Management, 6 December 1979.

3. ESD Business Management Handbook, Comptroller Business Management Division (ESD/ACBB), HQ Electronic Systems Division, Hanscom AFB, MA, 3rd edition, June 1979.

4. AFSCR 800-35, Independent Schedule Assessment Program, 31 January 1979.

Chapter Two

GANTT TECHNIQUES

Description

One of the earliest approaches to schedule planning control is a technique known as Gantt Charts. Named after its developer, Henry L. Gantt, the Gantt Chart was originated to help Frederick Taylor (The father of scientific management) display information for work planning and control. The set of Gantt techniques evolved into effective planning and monitoring tools for operations involving many tasks.

The concept of Gantt Charting is relatively simple. Down the vertical axis are listed the subjects of interest. The subjects may be tasks, organizations, or people. The horizontal axis is used to portray time according to some scale. Usually a bar depicts the length of a particular activity.

As an example, suppose we want to chart the major activities of business management people for the next year. The people become the subject and their planned activities might appear as follows:

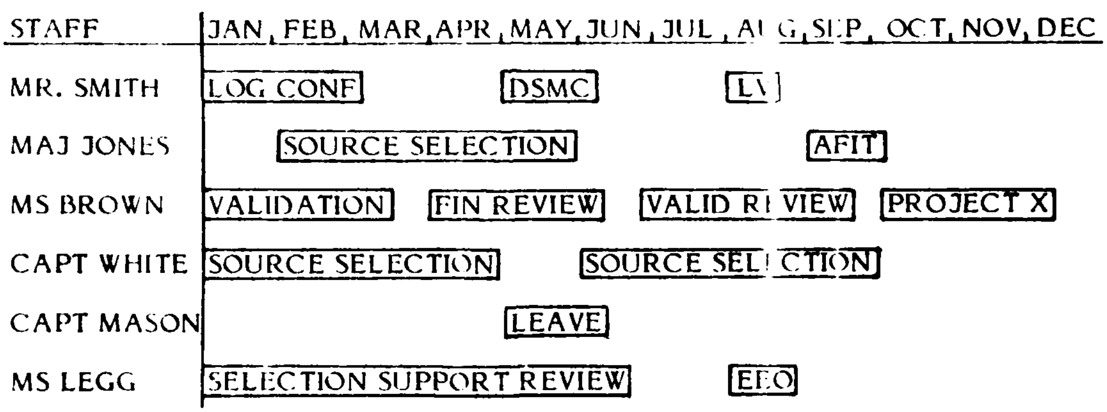


Figure 1

At the beginning of the year, Mr. Smith blocked out the major commitments of his people. He could have attached the planning process from the task end as well:

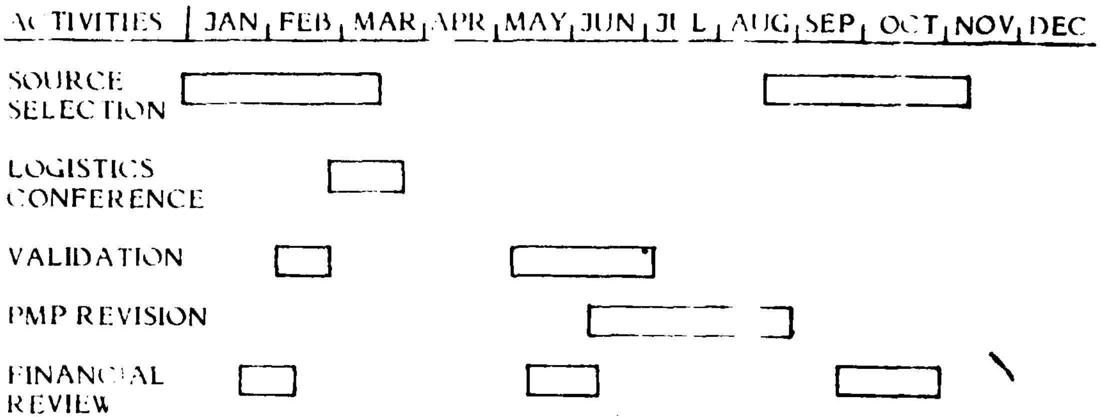


Figure 2

The time scale shown is the one most meaningful. The scale can be in months, days, or whatever. Sometimes the bars represent successive activities where one must be completed before the next starts, as in Figure 3.

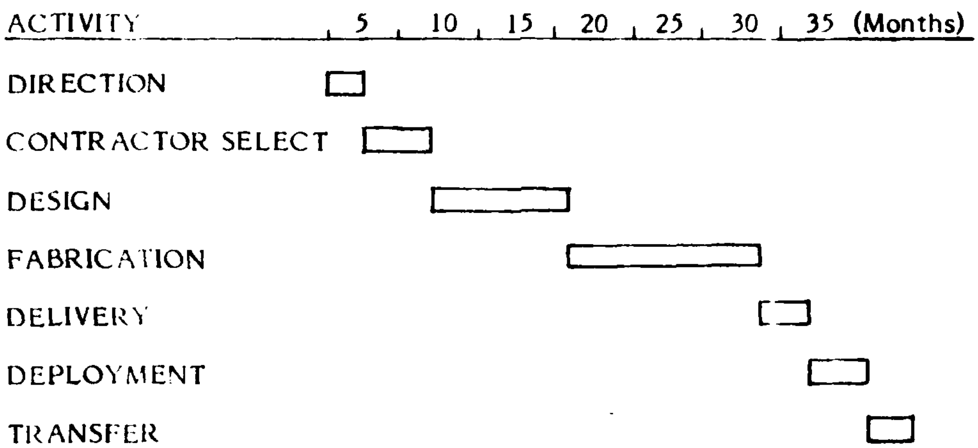


Figure 3

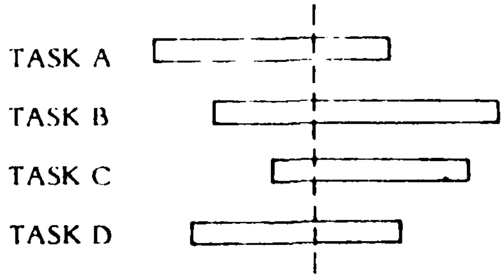
Gantt Charts with these characteristics are for obvious reasons often called waterfall charts.

There are a number of innovations to make Gantt Charts more useful; some of the more popular techniques are:

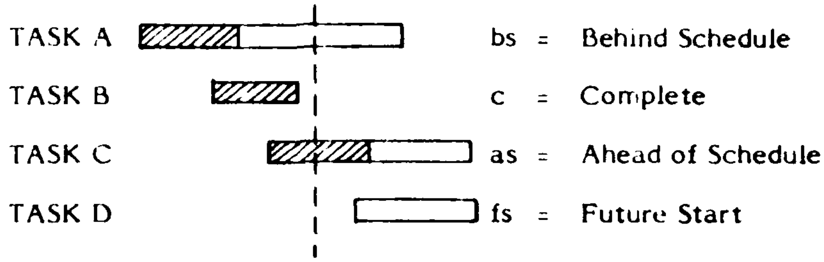
(1) Block shading to show progress.

TASK A  (Task 50% Complete)

(2) Show "as of" date with a vertical line



(3) Annotate with explanatory symbols



Strengths

Perhaps the greatest asset of a Gantt Chart is its simplicity both to construct and to communicate information. They are easy to develop and update and the mechanics are compatible with pen and pencil or computer controlled automatic plotters working from a data base. The sophistication depends on the purpose and the size of the job, but do not let color-coded window dressing influence your assessment of what is needed. Grease pencil on wall charts have been very successful and the fancy presentations require many hours of preparation.

The Gantt technique is quite good for showing the summary levels of a total program which will give a quick one page reference for the phasing of all major program activities. They are also very useful for expanding a single schedule task into the detailed activities that make it up. An example would be to show the time phasing of effort for the key people necessary to complete an activity. (This will come in handy when we cover Intermediate Schedules in Chapter 7.)

Figure 4 is an example of a repetitive process, the budget cycle, that has at least three different fiscal years being worked at any one time. The Gantt display shows this relationship quickly and simply.

PROGRAM BUDGET CYCLE

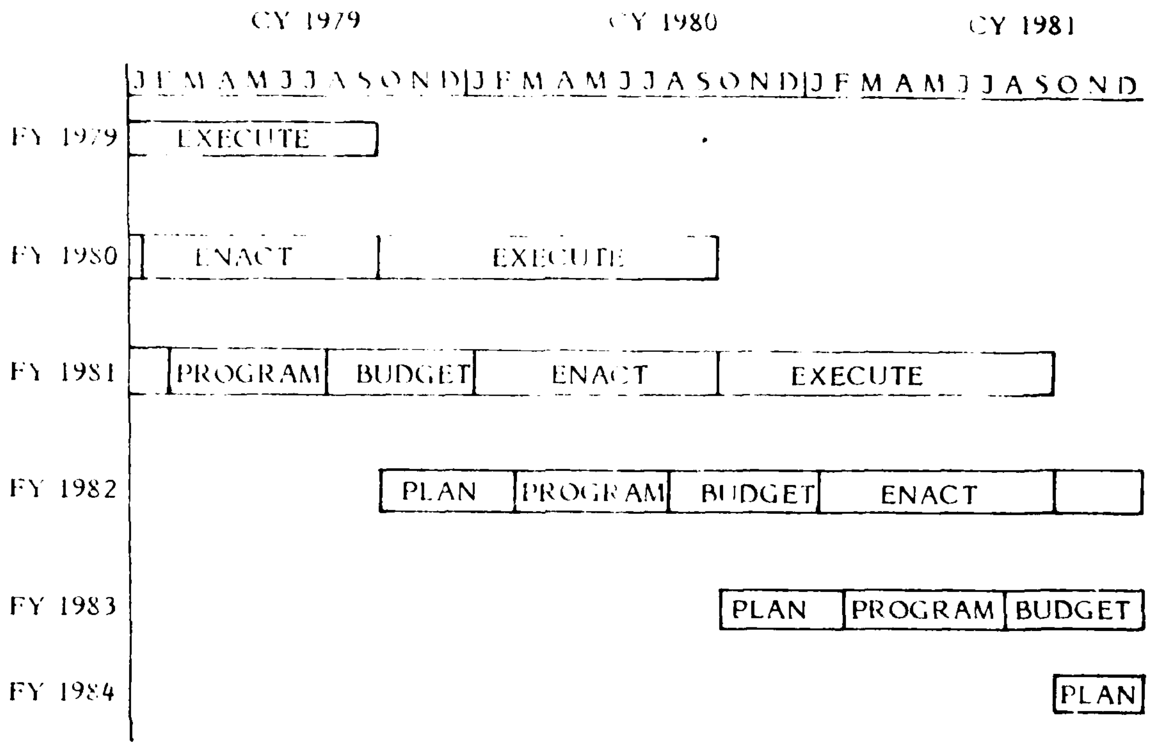


Figure 4

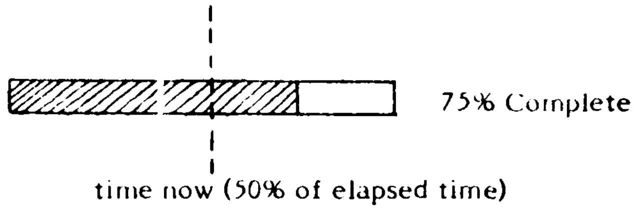
The Gantt technique works well if the activities scheduled are a fairly constant level of effort or a fixed resource that is being used to support multiple activities, such as test facilities or equipment. For more complex activities the Gantt Chart has limited capability.

Weaknesses

This brings us to what the Gantt Charts are not good for and the greatest weakness is the inability to show interactions between activities except on a very simple level. Don't try to use a Gantt display to lay out the detailed planning for any phase of a program. As soon as the number of activities becomes large (say more than a dozen) the Gantt Chart will cause more questions to be asked than answered about the relationship between tasks.

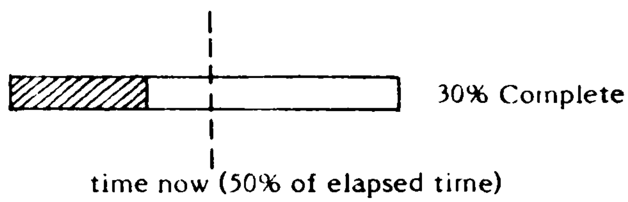
They also fall short when used to schedule activities that are complicated in nature. This is especially true when the progress display feature is being used. In other words, when the activity is not best discribed by the mere passage of time from start to finish, then a Gantt display can be a very misleading way to monitor performance. The following are a few examples of the confusion that can arise.

1. The task is front-loaded in terms of the effort and material resources required.



The display shows an ahead of schedule situation when it is in fact on-time; it should be 75% complete at this point. In some cases it could be behind schedule depending on how front-loaded the task is.

2. The bulk of activity is required toward the end of a task.



The task may be ahead of schedule, but shows up as late.

The point is that a Gantt technique is not designed to easily show completion progress on complex tasks and you can spend a great deal of time explaining artificial performance variances which detracts from the analysis of the real situation.

The Gantt approach is also deficient in showing actual performance versus the original planned schedule baseline. If the start and completion dates are different than the plan, there is no simple way to display that information. This leads to the next chapter on Milestone Schedules which is a modification of the Gantt Technique.

Chapter Three

MILESTONE SCHEDULES

Introduction

By far the most common scheduling technique at ESD is the milestone chart. Milestone schedules are prepared by the contractors as a contract data item or used by the SPO for a myriad of planning purposes. They are required for the Command Assessment Review (CAR) and Program Financial Reviews for Hq AFSC, and for a host of other briefings. A week does not go by within a typical SPO without the requirement to update and prepare a set of milestone charts for one reason or another.

The milestone technique itself is quite simple. For a particular activity, a set of key events are selected. A milestone is an event that should occur if a particular activity is to proceed as planned. In Figure 5 the activity being scheduled is the engineering development phase of an ESD project. Milestones were selected based upon the SPOs plan for accomplishing the engineering development phase. By reviewing the status of these milestones, we can assess the overall schedule status of this activity.

Description

The milestone type of schedule uses a fairly standard symbology consisting of arrows and diamonds, or some similar system, to show originally planned event dates and changed dates. Figure 6 shows the symbols we use on the AFSC Form 103, Program Schedule, and the interpretation of various combinations of the symbols.

Figure 5 shows the application of the symbology from Figure 6. Line 4, ADPE Installation and Check out, was completed one month ahead of schedule. Both lines 6 and 7, Equipment Integration and Software Development were initiated one month behind schedule. The diamond symbol can be used to show events that are rescheduled to account for changes as a program progresses while the diamonds retain the originally planned schedule. So the milestone schedule allows us to improve on the Gantt chart by monitoring actual performance, retaining the baseline dates, and incorporating changes in the plans for future events.

Note that the milestone scheduling technique is limited to telling us what has happened or incorporating changes in plans projected from other sources. It is not very useful for forecasting future schedule changes like the Network or Line of Balance techniques that we will cover in the next two chapters. The milestone schedule simply records the manager's assessment. For example, a manager might reasonably predict that the one month slip in the start of software development will probably result in at least a one month slip in the completion of the engineering development

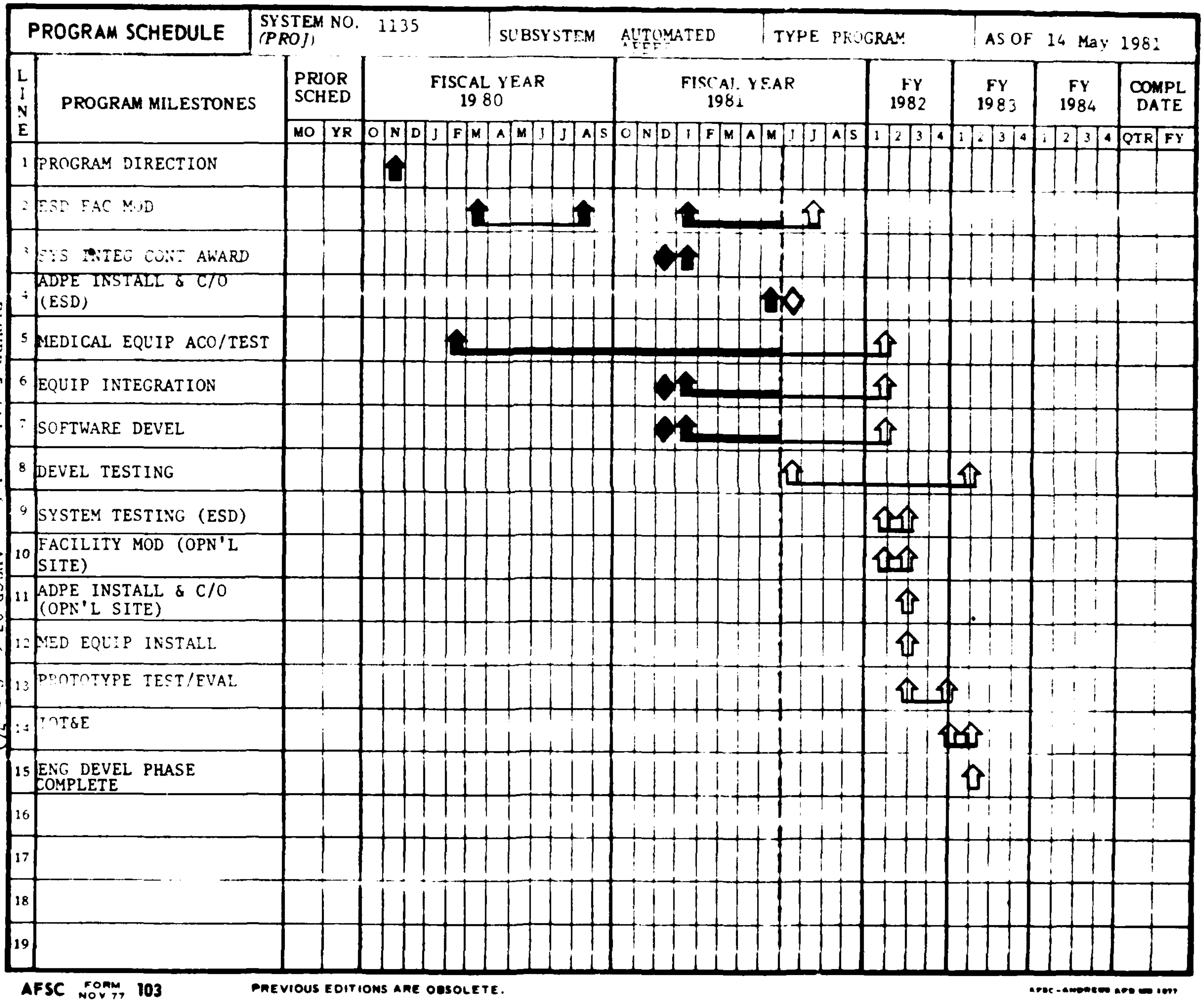


FIGURE 5 (Adapted from AFSCR 27-6, Sep 74)

SYMBOLOGY AND USE

Standard symbols have been adapted for Air Force Milestone Schedules. The most common symbols use and their meanings are shown below:

BASIC SYMBOL		MEANING
⇧	......	Schedule Completion
⬆	......	Actual Completion
◇	......	Previous Scheduled Completion-Still in Future
◆	......	Previous Scheduled Completion-Date Passed

REPRESENTATIVE USES		MEANING
◇ ⇧	......	Anticipated Slip-Rescheduled Completion
◆ ⇧	......	Actual Slip-Rescheduled Completion
◆ ⬆	......	Actual Slip-Actual Completion
⬆ ◇	......	Actual Completion Ahead of Schedule
⇧—⇧	......	Time Span Action
⬆—⇧	......	Progress Along Time Span
⇧—⇨	......	Continuous Action

Figure 6 (from AFSCR 27-6, Sep 74)

phase. The milestone schedule does not tell him that - his experience does. This is key to understanding the use of milestone charts. Unless we understand the activity and the interrelationships of the milestones, the chart only tells you what has happened. However, if we couple the information on what has happened to the available experience/knowledge, we can determine what may happen in the future.

Milestone charts are also used to lay out the detailed scheduling within most contractor Cost/Schedule Control Systems. This includes planning and performance measurement down to the level of individual work units or packages which can number in the tens of thousands on a large contract. This quite naturally leads to an automated system and the milestone approach is very amenable to a computer treatment. However, heed the cautions in the last section on automated milestone systems.

Structuring a Milestone Schedule System

For a complete large-scale milestone system the key is a well structured organization of the various levels of activities scheduled. This structure must relate to both the product (equipment and services) to be delivered and to the organizations (or individuals) responsible for performing the work required. A structure that accomplishes these requirements is necessary to fulfill the DOD Cost/Schedule Control Systems Criteria (C/SCSC)(see AFLCP/AFSCP 173-5 C/SCSC Joint Implementation Guide, p.14) for contractor applications. The basic framework is the Program Work Breakdown Structure (PWBS) which is the product oriented description of the total job to be done. Military Standard 881A explains the WBS and its application to the generic types of defense systems (electronic systems for ESD). AFR 800-17 implements this MIL STD for Air Force acquisition programs.

The PWBS describes the program in levels where level one is the system to be delivered, level two divides this into the major system equipment and services (Prime Mission Equipment, System Test and Evaluation, System/Project Management, Data, etc.). Level three expands each level two item into its major components, and each succeeding level adds more detail to form a tree structure. Many Contract WBSs extend to level six or lower, which can encompass individual WBS items numbering in the thousands.

The Responsibility Assignment Matrix concept adapted from C/SCSC links the performing organizations with the parts of the WBS they are responsible for. This can be used for both total Program and Contract WBS's, but remember, the various contracts can only form a subset of the total program activities that a PWBS must describe.

The milestone schedules are used to lay out the activities and events in any of a number of cross-sections from this matrix. Figure 7 shows a part of a Program WBS Responsibility Assignment Matrix. The intersections identify both the work and the workers and schedules can then be called out by responsible organization, by WBS item, or both. The level of detail is

RESPONSIBILITY ASSIGNMENT MATRIX

Responsible Organizations

Work Breakdown Structure Level: 1 2 3

Work Breakdown Structure	ESD/SPO	MITRE	CONTRACTOR A	CONTRACTOR B	USER (TAC)	OPERATOR (AFCC)	LOGISTICS (AFLC)	TRAINING (ATC)	TEST (AFTEC)	RADC	ECAC	PACAF	USAFE
System ZX													
Prime Mission Equip.			●	●									
Integration & Assem.			●										
Radar			●							●	●		
Commun. Equip.			●							●	●		
ADP. Equip.			●										
Software				●									
Displays				●									
Auxiliary Equip.			●	●			●						
Training													
Equipment			●	●				●					
Services			●	●				●					
Facilities					●	●		●					
Peculiar Support Equip.			●										
Systems Test & Eval.													
Development Tests	●	●	●	●			●		●	●			
Operational Tests	●	●			●	●	●		●				
Test Support			●	●	●							●	●
System/Program Mgt.													
System Engr.	●	●	●	●									
Project Mgt.	●		●	●									
ILS	●	●	●	●		●	●					●	●
Data			●	●					●				
Site Activation			●	●	●		●					●	●
Common Supp. Equip.	●						●						
Initial Spares	●		●	●			●						

Figure 7

varied by the WBS level required. As stated earlier, the contractor application of this system will include schedules at levels five and six of work planning and performance in many areas of the WBS. The Program Office application will normally be limited to a higher level for practical maintenance of the system. (See Chapter 7 on Intermediate Schedules for more guidance.)

Strengths

As with the Gantt chart, the milestone schedule can be a very effective method of communication. The symbology is relatively standard and simple to use. It also allows the presentation of actual progress against a baseline plan and changes in future plans. The mechanics to construct milestone schedules are also relatively simple, although it may seem that we spend too much of our time with stick-on arrows and diamonds and the AFSC Form 103. As described earlier most of our contractors use milestone schedules extensively and they are usually the type submitted for the Program Schedule contract data item (data item description (DID) DI-A3007) as well as their use in the Cost/Schedule Control Systems.

One very useful adaptation has been used for work performance measurement. This technique is shown in Figure 8 below and consists of a number of significant milestone points for an activity that correspond to some measureable interim completion values. These are called "value milestones" and in this example the first milestone accomplishment represented 15% completion after all purchased parts are received to begin assembly. The second milestone increases to a 65% completion as major subassemblies are all completed. This continues to 100% after completion of final tests.

Component Assembly and Checkout

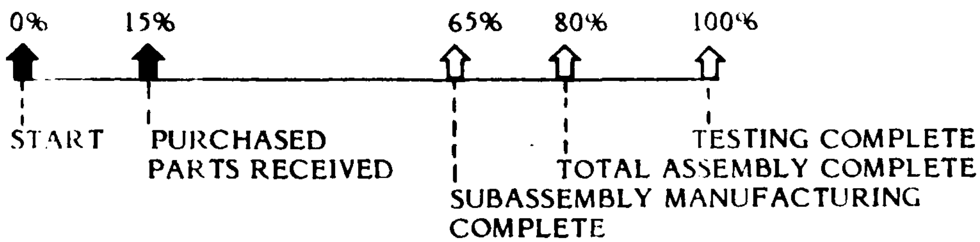


Figure 8

As these more complex applications of milestone schedules are encountered we must remember that this scheduling approach is giving us a limited view of what is in fact a network of activities. Milestone charts are used to portray results derived from network analysis or a line of balance computation which is a variation of networking. We will cover these in the following chapters, but this points up the deficiencies of the milestone approach that we must keep in mind.

Weaknesses

As with the Gantt chart, a major weakness of the milestone technique is the lack of a mechanism to show interdependencies or interaction between activities. Although milestone schedules are used extensively on complex programs, they are usually the product of some type of network analysis. In fact, the milestone technique is a good way to display various areas of a network in a more familiar form, and we will look at this concept in detail in Chapter 7 on Intermediate Schedules. The danger lies in our tendency to focus on the milestone format and lose sight of the true complexity of the relationship between the tasks we are dealing with and the total program.

The Responsibility Assignment Matrix structure discussed earlier does give us a way to relate a large number of milestone events, but this technique is simply setting up the first stages of a network and a full network teatment should back it up. As an example of the problems with the strict milestone treatment, look at Figure 7 again. A milestone schedule that shows all of the major events for the WBS item Systems Test and Evaluation, Development Tests is backed up by functional schedules from seven responsible organizations. Each of these organizations must accomplish certain key activities to complete testing for this system. The milestone technique will not tell us what the sequence of activities must be, where the constraining points are, and which activities are most critical for management attention. In fact, there will be many opinions about the above information, but the manager will be left to sort it out. The milestone technique will not show it to us.

This type of problem becomes non-trivial quickly as the WBS level being scheduled increases. There is an ever-present danger that activities which show up on product (WBS) oriented schedules and on several different functional schedules may change in one place while the impact in other areas is not realized until too late. Again, milestones do not depict interactions, the manager must find them out.

Most programs require the contractor to submit milestone schedules. The contractor is generally expected to select the milestones which he or she believes will indicate the overall status of activities. The data item description normally allows the government to approve of the milestones which are selected for periodic reporting. <u>BEWARE!</u> There are many traps in this area. First, do not let the contractor report milestones which no one in the SPO understands. Avoid cryptic abbreviations. Avoid generating a host of alphabet soup. The schedule is meant to communicate information. It can not do that without careful selection of the milestones. If you don't understand every line in a contractor's schedule have it explained to you.

Another danger to avoid is the tendency for "micro-management." For example, one of the writers had a contract with a large contractor who had automated a technique for producing milestone schedules. Working with the SPO, generic milestones were identified for reporting. Since the SPO software engineers had expressed a requirement for Computer Program

Component (CPC) level visibility below the Computer Program Configuration Item (CPCI) level, a generic set of eight milestones were selected for each CPC. Milestones such as start and complete design, and start and complete coding were at first considered reasonable types of milestones. Not until the SPO had let the contractor implement this type of schedule did we realize that there were more than 400 CPCs and that the software milestones would therefore number 3200. Similar mistakes were made in other disciplines with a net result of a program milestone schedule which had 10,000 events. Needless to say, the presence of so many "trees" prevented anyone from even finding the "forest." Remember, micro-management can kill.

Select milestones by having each functional Division Chief determine what he or she considers important. Keep count of the milestones that he is requesting and avoid the CPC reporting problem above. Get feedback on the utility of the first few schedules from each division and revise the schedule accordingly. Work closely with the contractor in developing a schedule which will communicate information. Your requests for changes to the contractor's submission can be made as part of your official comments on the data item.

Another problem with milestone schedules is in determing whether the time depicted for an activity is reasonable. Past experience on other programs or independent assessments by the SPO divisions are good techniques, but tend to be subjective because of the lack of a credible data base of historical experience. However, if your contract requires a Cost Performance Report (CPR) and the validation of the contractor's C/SCSC system, there is another method for determing the reasonableness of a particular schedule.

The contractor's C/SCSC system is required to have a scheduling system which meets certain criteria. An essential criterion is the ability for schedules at the work package level to support and track to the schedules at the cost account level. Similarly, the cost account schedules must support and track to the intermediate schedules and to the master schedule. For any item on the milestone schedule, the contractor should be able to demonstrate that lower level schedules support this item. These lower level schedules can be reviewed upon request. If you are lucky enough to have a data accession clause on your contract, you can also request copies of the lower level schedules which support a particular item. However, beware once again of micro-management. A $40M contract can have over 5,000 work packages - each with a schedule. Insure that you use these requests sparingly to support a one-time review of a critical area. Do not allow yourself to get dragged into the trees. On the other hand, don't be afraid to use this data. Spot checks help insure that the contractor's schedules are credible.

Most milestone schedules from the contractor contain a narrative describing why changes occurred. This narrative is never complete and there is a tendency for SPO Divisions to bombard Business Management with

data item comments such as "Why did this slip?" or "Why will this item take three months?" Do not accept these comments blindly and forward them to the contractor. A SPO cannot afford to communicate with the contractor solely or even primarily through the monthly schedule. If someone has a question, let him call his counterpart at the contractor's and ask the question. The only times that formal questions should be included in your data comments are when the contractor refuses to provide an informal answer or when the SPO OPR wants the answer formally documented for some reason. These questions should be limited. Answering these questions can tie up a significant portion of the contractor's management resources - resource that could probably be better applied elsewhere.

Milestone schedules require a significant amount of effort to generate. Searching out the status of an item consumes more time than making the chart. Answering questions adds to the time. If you have ever developd a set of milestone charts for a Program Financial Review or for an internal review you can quickly appreciate the amount of effort required. Remember this when you ask the contractor to do something.

Chapter Three References

1. AFSCP/AFLCP 173-5, Cost/Schedule Control Systems Criteria Joint Implementation Guide, 1 October 1976. (pages 10-16, especially p. 14 and 16, para. 3-3.c.)

2. MIL-STD-881A, Work Breakdown Structures for Defense Material Items, 25 April 1975.

3. AFR 800-17, Work Breakdown Structure (WBS) for Defense material Items, 2 May 1975.

Chapter Four

NETWORKING

Introduction

In the previous chapters we have frequently cited the lack of a mechanism to show the interdependencies of schedule activities as a key weakness of the Gantt and milestone techniques. Network analysis is designed to perform precisely that function. This approach diagrams a schedule by the flow of activities that make it up in the sequences and patterns that actually relate the tasks. Network techniques are indispensable to systems analysis in engineering the technical aspects of our systems. Applying a similar approach to scheduling is simply a recognition of the complexity of the job we are dealing with.

Before we even begin a description of network techniques we must deal with some of the criticisms of them as management tools for planning and control. There is no escaping the fact that networking is a major undertaking for any program. The level of effort is high initially, and the questions that must be answered to identify the real relationships and constraints between program tasks will involve almost every individual with a responsibility to do a job. But, the process of constructing the network in itself will prove a valuable experience to the program, because you will find that many channels of communication will be opened up that would not have existed otherwise. We will describe this process in more detail in Chapter 6.

Description

The term "networking" refers to any of a group of techniques that portray the elements of a system in a scheme that explicitly defines the relationships between the elements (i.e. sequences of operations, combination and divergence points, and the operations that occur between points). When applied to schedules a network diagrams the activities or tasks that are required and relates these activities in terms of their initiation and completion points. As with the milestone approach, any single activity can usually be broken down into the subtasks that make it up, or a group of activities can be aggregated into a single equivalent schedule task with one set of start and complete milestone events. So the level of detail can be adjusted to fit the application.

The first use of network analysis for scheduling large engineering projects was initiated in 1956 by private industry for their own use and this was quickly followed by an application on a defense development program for the Navy, the Fleet Ballistic Missile - POLARIS. The initial project was called the Critical Path Method (CPM) and the Navy application was the now famous (or infamous - depending on your viewpoint) Program Evaluation

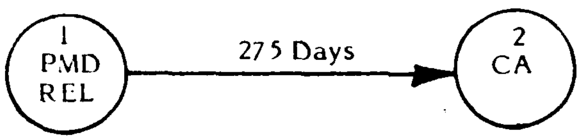
and Review Technique (PERT). Chapter 1 of reference 1 gives a good account of these developments.

PERT and CPM are both fairly standard techniques and widely used now. There is, however, a great amount of management emotion associated with these acronyms, both pro and con. We will not get involved with the controversy at this point. Both are very similar approaches to schedule networks and that is our subject now. Both also use the same basic symbology which is where we will begin.

Symbology

The basic graphical ingredients for a network are a symbol for the "point in time" events or milestones that start and stop each activity (usually a circle or box) and an arrow between the events to represent the activity itself. The direction of the arrow is from start to finish.

To start with an example, consider the activity on a program between the initiation of the effort by the release of Program Management Direction (PMD) by Hq USAF and the first desired result--the start of development work by a contractor at contract award (CA). The network description is shown below.

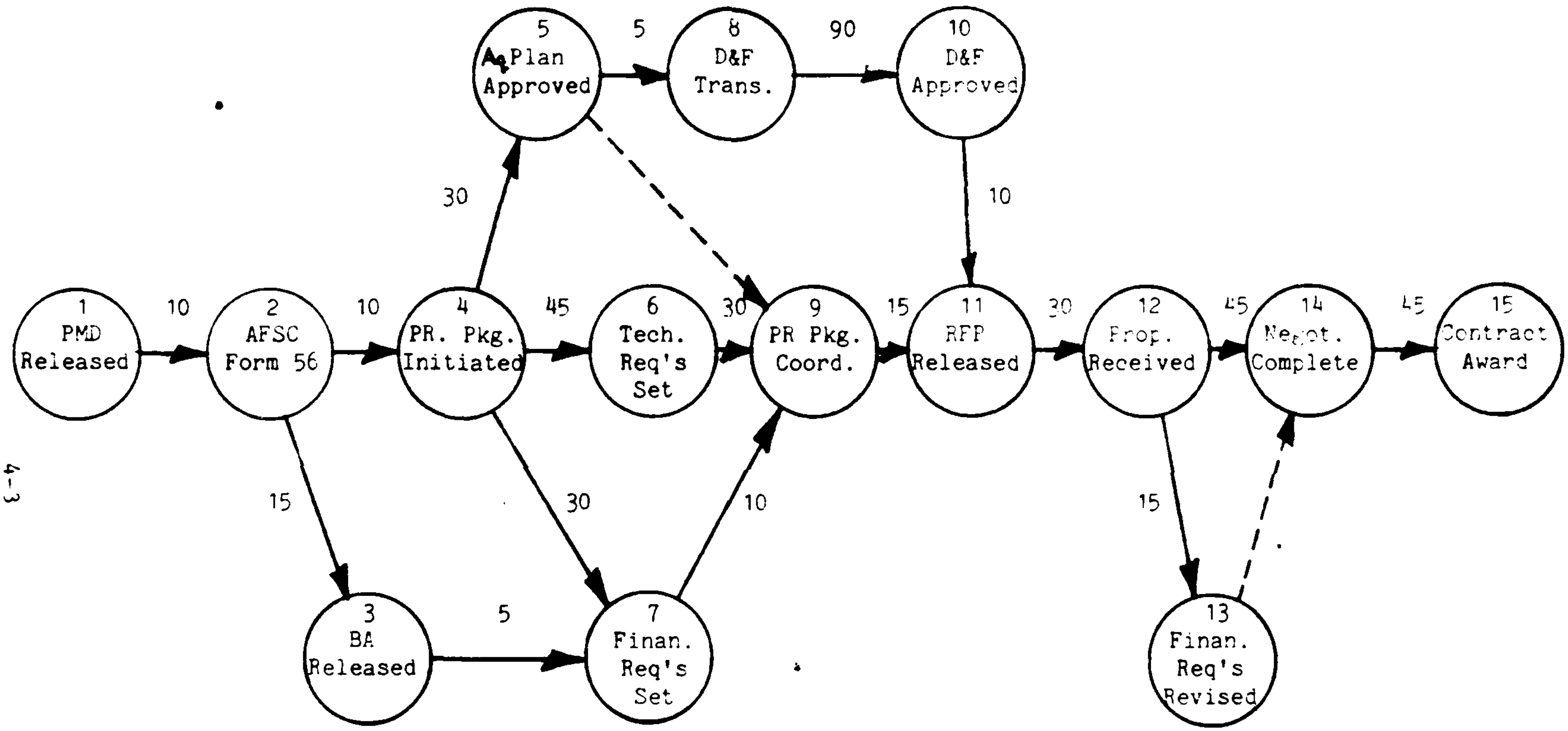


We have two milestones and the activity between points 1 and 2 is estimated at 275 days to complete. Now we will look at an exploded view of the activity to show a complete network in Figure 9.

This network spans the same initiation and completion points but now there are 17 activities and 15 events describing the process to obtain a contract award. The events are numbered so that any activity proceeds from a lower number (predecessor event) to a higher number (successor event). An activity is a process that consumes resources over a period of time. The movement from one event to the next must represent progress toward the final goal; if it does not, then you have not chosen meaningful milestones for the events. The only exception is the use of "dummy activities," shown by a dotted arrow, that do not indicate a time span--only a dependency between events.

In Figure 9, the activity from points 1 to 2 is the coordination process at Hq AFSC that results in the issuance of an AFSC Form 56 tasking one of the Product Divisions (here ESD) with carrying out the PMD requirements. The duration is estimated at 10 days. Proceeding through the network, the AFSC Form 56 release initiates two activities. Activity 2-4 is the internal ESD coordination that assigns the PMD task to a SPO and makes an assessment of resource requirements; the result is the initiation of the Purchase Request (PR-AFSC/AFLC Form 36) package that will define the

PROGRAM NETWORK EXAMPLE



NOTES: -Activity duration shown in calendar days above activity line.
-Critical path (1-2-4-5-8-10-11-12-14-15) = 275 Days.
-This is only an example!

Figure 9

specific contractual requirements. Activity 2-3 is the effort to release a Budget Authorization from Hq AFSC that transmits the funds for the program to ESD (the overall program budget requirements would have been submitted and approved prior to the PMD release).

Event 4 precedes activities 4-5, 4-6, and 4-7 which are in sequence: preparation and coordination of an Acquisition Plan that lays out the business and contract strategy for this effort; translating the program's technical requirements into exact contractual language; and setting the financial requirements for the contract including estimates of the types of funds and the time-phased amounts needed for this contract effort. The final coordination of the Purchase Request package (point 9) is constrained by the approval of the Acquisition Plan, in this case.

The next point showing dependency is point 11, the release of the Request for Proposal (RFP) to the industry source. (The RFP is prepared by the Deputy for Contracts based on the PR package.) This action is constrained by the receipt of the Determination and Findings (D&F), approved by the Secretary of the Air Force, which grants the authority to negotiate a contract.

Activity 11-12 represents the 30 day period for the potential contractor to prepare the proposal. Once the proposal is received, there is frequently a need to revise our assessment of the financial requirements (activity 12-13). This must definitely be accomplished before negotiations are completed and the constraint is shown by dummy activity 13-14. The final task (14-15) is contract writing, final approval, and distribution. (This example is representative of pre-contract award activity in a fairly simple case, but each activity shown here could be broken down into further tasks and relationships. Also, the time estimates are not necessarily accurate.)

Network Analysis

With the basic symbology established, we can now start the analysis of the network. This will be an abbreviated treatment of the subject since any of the sources referenced at the end of this chapter give several hundred pages of detail and applications. You will find many other sources as well.

The first step is to find the longest path through the network, and in PERT and CPM this is termed the "critical path." For the example in Figure 9, the critical path follows points 1-2-4-5-8-10-11-12-14-15 and the duration is 275 days. You must add the durations sequentially for all possible paths to find the critical path. In this case two other paths are: 1-2-4-6-9-11-12-14-15 = 230 days, and 1-2-3-7-9-11-12-14-15 = 175 days.

The critical path in a network becomes the focus of management attention because any slip in the completion of an activity will cause an equal slip in the final milestone, assuming that the other activities remain the same. With the same logic, a decrease in the duration of any critical path activity will decrease the duration of the entire network. That is true until one or more of the other possible paths takes over as the critical path. That introduces the next key concept which is called "slack time."

Slack time refers to the difference in duration between the critical path and an alternate path at any point in the network. For example, in Figure 9, the slack in path 1-2-4-6-9-11, at point 11, is 155-110 45 days. That means path 1-2-4-6-9-11 could increase by 45 days before matching the critical path length, or if the D&F approval (activity 8-10) was obtained in 40 days instead of 90, then it would no longer be on the critical path. The slack time varies at each point in the network, and the amount of slack at the start of any activity can be a good indicator of the importance of its schedule performance to the overall project.

For a large-scale network the critical path and slack time calculations are made by what are called "forward pass" and "backward pass" operations along all paths of the network. The forward pass establishes the earliest expected completion (EEC) dates for each event by adding the expected activity durations to that point (the longest time is used for points where several paths merge). The backward pass starts at the final event and traces the paths back to the start point. This establishes the latest allowable completion (LAC) date for each event by subtracting the activity durations from the LAC for the previous event. The difference between the earliest expected and latest allowable completion dates at each point is the slack time for that point. Along the critical path the slack is zero. (EEC and LAC times are the same).

With the concept of slack we can see the importance of the estimates of the time required for each activity. The critical path may be something quite different than we expect if the accuracy of time estimates is not taken into account.

Time Estimates

The most difficult characteristic to define for any activity is the expected duration to complete it. This time estimate will set the benchmark that schedule performance is measured against, but that performance track record for both industry and government is far from good. There seems to be a constant interaction between the expectations and interpretations of the asker and the doer when we develop time estimates. The nature of that interaction is not very well understood in many cases. Reference 1, page 78, gives a humorous account of the interaction between an individual and the boss during the negotiating of a "reasonable" duration for a production run. Both are participating in a gaming process where each is trying to anticipate the other's logic and expectations with the result being a little dubious to both.

One of the first appproaches to improve estimates is to break an activity down into greater detail and estimate smaller pieces of it. That is the basic rationale for the network approach because it allows us to add many smaller activities to give an expected duration for a single overall task. But, we are still faced with the problem of estimating accuracy for the lowest level activity. The next technique to improve accuracy is to use multiple estimates for each activity.

The efforts that we normally deal with in acquisition scheduling are not always well defined and frequently have not been done before, at least not in the way that is required for a particular program. If the product is not new in some way, then we would not be given the job. This means there is a degree of uncertainty involved and the time estimates should take that into account. The use of several time estimates that are combined through some weighting scheme is a good approach and PERT employs such a technique. We will discuss the merits of the PERT technique in Chapter 8 in some detail and offer an alternate scheme to deal with uncertainty in a quantitative way. At this point we will only look at the PERT scheme, which is used widely in our business.

The objective of the estimating process is to arrive at the length of time for an activity that is the best representation of the range of possible circumstances that may occur. We will leave the statistical details for Chapter 8, but the "expected time" is the characteristic that best describes an activity for purposes of network analysis. This is the mathematical approximation of a 50% total probability of occurrence or a weighted average time.

In PERT the expected time is derived from three time estimates for a single activity, these are:

1. most optimistic time (a)

2. most likely time (m)

3. most pessimistic time (b)

The most optimistic time estimate is about the shortest possible duration for the activity assuming that everything required happens in the most time efficient manner. Again, see Chapter 8 for the statistical assumptions, but this represents about a 1 in 100 chance of occurring. There is also no assumption of unusual external influences or interference from the results of any other task.

The most likely time estimate represents the duration that would occur most often for a repetitive activity or has the greatest chance of occurring for a one-time activity. This is not necessarily the same as the 50% cumulative probability point, hence the need for this treatment.

The most pessimistic estimate is at the far end of the range of possibilities and has about a 1 in 100 chance of being exceeded. Again, there is no assumption of unusual external influences (acts of God, strikes, etc.) and it should not take into account the outcome of any other task. Each activity must be estimated as a stand-alone entity from the network (statistical independence).

The expected time (Te) is then given by the following formula:

$$Te = \frac{a + 4m + b}{6}$$

This approximates a cumulative 50% probability of completing the activity in that time or less. The formula was derived by the developers of PERT and is a simplified form of a more complex relationship.

The expected time estimate is the value that should be used for the network calculations, but remember it is an average duration that should give a 50/50 chance of accomplishment on or before that point in time. There are useful techniques for developing confidence intervals for network points that will answer questions such as: "At what point in time will we have a 75% or 90% chance of completion based on the estimates?" We will present these techniques in Chapter 8.

The important concept here is to use some consistent and logical scheme to integrate multiple time estimates for each activity in the network. These multiple estimates can come from the same source or multiple sources but you will find that most estimates will be derived from question and answer sessions with program office and contractor personnel.

Strengths

Network schedules give us the logic and organizational structure to combine many activities and incorporate the complexity of the relationships between tasks. This lets us gather schedule information from all available sources within a program and then integrate that data in a graphical form that clearly shows what we know about the way the program will be executed. At the same time the process of building the network will highlight what we don't know and give us the chance to fill in the gaps where possible.

A network is ideal for the planning phases of a program when there is still some flexibility in the time-phasing of activities. A good network analysis of a program sets a firm foundation for getting things moving in an orderly fashion when the go-ahead is received for a project. If this initial effort is tied in with an organizing scheme such as the Responsibility Assignment Matrix, discussed in Chapter 3, products from the network schedule can be extracted either by responsible organization or the WBS items. We can thus provide sub-schedules for the effort that a program participant must accomplish over a period of time (this could be a simple milestone chart or a network in itself). These products are well suited to documents such as the Program Management Plan (PMP). AFR 800-2 states that the PMP is directive on program participants!

A network schedule can be developed at any level of detail and the more detail we can incorporate the greater the accuracy of the schedule predictions. No one will argue much with a very generalized schedule of the program, but as soon as we start showing the level of detail that explicitly defines the interactions between groups for specific tasks there will be plenty of feedback. Some of the exchanges may be emotional as an individual feels his area of responsibility is being encroached, but they will be exchanges of information. That is the objective in the first place!

Network analysis can be used at any phase during a program's life cycle, but the objective and the use of results will vary. An analysis performed during the Full Scale Engineering Development phase may indicate that we have a low confidence of meeting the directed date for an Initial Operational Capability (IOC). That may be a very unpopular result, since most program parameters are already set (especially the budgets). But this type of analysis can give ideas of where to concentrate on improving schedule performance. It may also show us that current plans cannot be accomplished and should be changed!

Weaknesses

There have been strong arguments voiced against the use of large network schedules as a management control technique. These criticisms have centered on the PERT and CPM approaches, but apply to networking in general. Once an effort is underway a large network can become unwieldy to maintain as plans inevitably change. PERT-type efforts to control entire programs or contracts within a program can collapse of their own weight. The result may be a monthly report that is simply a minor rehash of the initial plan and not descriptive of the current situation. With networks bigger is rarely better.

A network is an approach for setting up a management information system. There are other ways of fulfilling the information needs of project management (i.e. planning, organizing, directing, and controlling), but no approach will work unless we properly scope the amount of effort needed to support it and make a conscious decision to commit those resources. A network-based system can require a relatively large amount of time to setup and maintain, although the degree of the application can be tailored by the level of detail incorporated (and that is our suggested approach).

If there is not a clear commitment by upper level management (SPO Director and Division Chiefs) to implement and use a network system it will not be a medium of information exchange. The management style of an organization is chosen by the boss, either explicitly or implicitly. It soon becomes obvious to the members of an organization what information the boss thinks is important and this is where the real effort is focused.

Computer based network systems are the next area of problems. Large network applications are normally automated to some extent since the amount of data being maintained is extensive. Most contractor developed schedules are some form of automated network. Although there are efforts in process to provide this type of computer support to our program offices, the access to these resources is limited at this point, so we have a very limited ability to handle large-scale networks internally.

The PERT and CPM systems have also been criticized for their tendency to focus attention on the critical path only. In Chapter 8 we will show the mathematical detail, but there can be a considerable amount of "optimistic bias" in the expected time predicted by the single critical path calculations. We can get a general idea of the extent of the problem for any application by identifying the number of alternate paths through the network that are close in total length to the critical path (say within a few

96). The slack time will be low on these paths. If there are multiple paths close to the critical path length, then the expected time will be optimistic to some extent and a more complex method should be used.

Chapter Four References

1. Archibald, Russell D. and Richard L. Villoria, Network-Based Management Systems (PERT/CPM), John Wiley and Sons, Inc., New York, 1968.

2. Moder, Joseph J. and Cecil R. Phillips. Project Management and CPM and PERT, Reinhold, New York, 1964.

3. Battersby, Albert, Network Analysis for Planning and Scheduling, Saint Martins Press, Inc., New York, 1964.

4. AFR 800-2, Acquisition Program Management, 14 Nov 77.

Chapter Five

LINE OF BALANCE

Introduction

The line of balance technique is a special application of networking that is used for many repetitions of a set of activities, such as on a production effort. It is a good mechanism to provide overall schedule status information for a large project and will pinpoint problem areas for a more detailed analysis. A line of balance system is not typically developed or maintained by a program office, but they are employed by contractors on many of our systems.

Description

The basic idea for the line of balance is to time phase a large number of identical networks by setting the planned completion date for each one and then backing up the events that comprise it to find when they must be accomplished to meet the planned date. Since each network is identical (as with manufacturing operations) we can find out how many of each type of event must occur at any point in time to met the objectives.

The line of balance consists primarily of three components; the objective, the program and the progress chart. It is the particular line on the progress chart that gives this technique the name "Line of Balance." Contractor reports[1] will contain the actual graphics portraying these three components, and we will look at how each is constructed to make this product useful to the program office.

The first component of the line of balance system is the objective which is a graphic display of the cumulative end item delivery forecasted (typically what is called for in the contract). The actual experience to date would also be shown. For the example, shown in Figure 12 (stolen from our sister service,reference 1), the contract called for 30 units to be delivered by the end of April. Only 14 have been delivered. Using the fingers and toes of you and your neighbor, you can easily see that delivery is falling behind by 16.

The second component is the program. This is a flow diagram representing established events (control points) for the process. These points are the key material, component, fabrication or assembly points necessary to deliver the end item. The lead times for these points are shown graphically on the chart or against the scale on the bottom. What are

[1] The Air Force Data item for this is a Production Analysis Report, DI-P3455/P-109-1; the Army has used DI-P-1607, Line of Balance Reports; the Navy has used UDL-A-23001, Chart, Line of Balance.

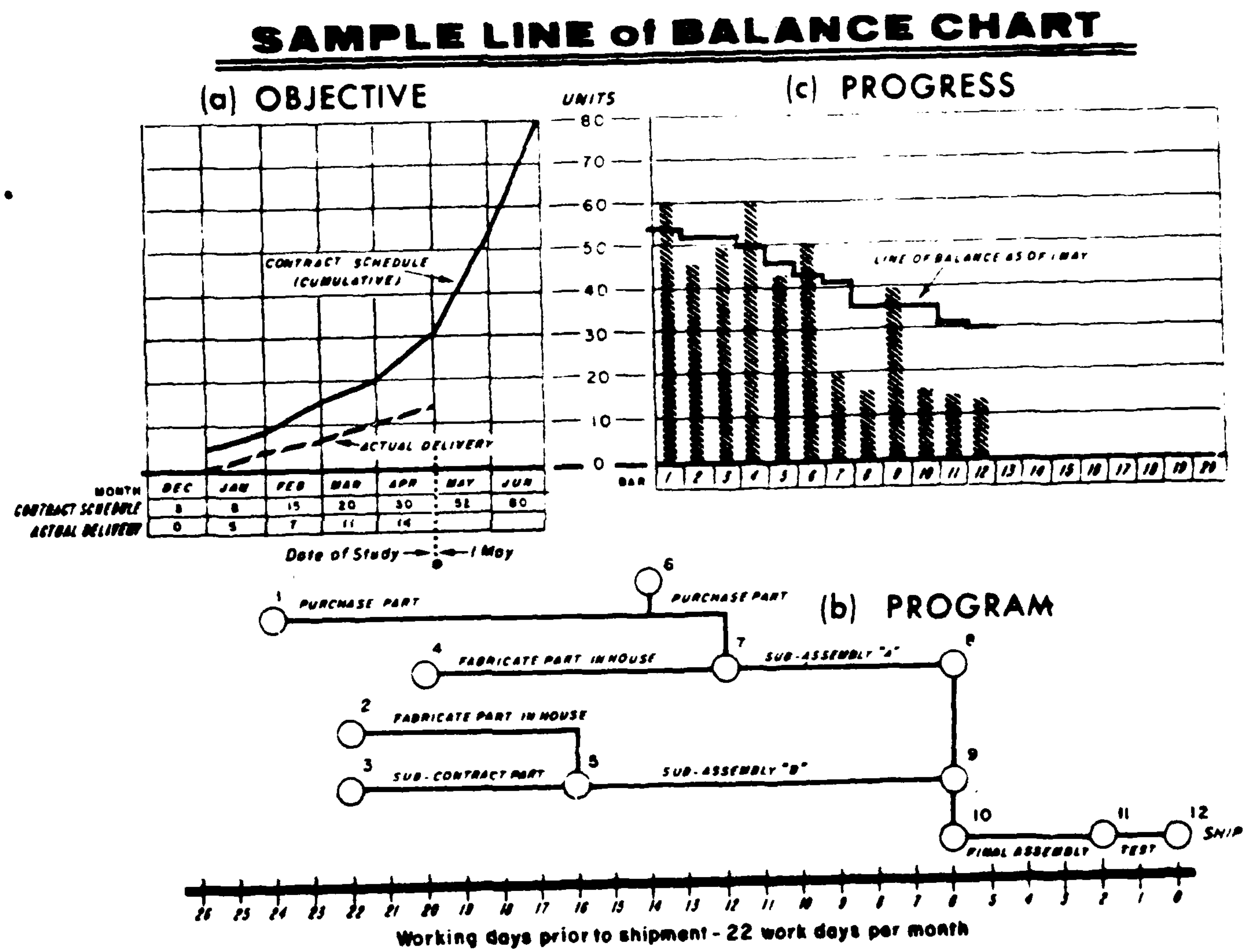

SAMPLE LINE of BALANCE CHART
(a) OBJECTIVE
(c) PROGRESS
UNITS
CONTRACT SCHEDULE (CUMULATIVE)
ACTUAL DELIVERY
MONTH
CONTRACT SCHEDULE
ACTUAL DELIVERY
Date of Study
1 May
LINE OF BALANCE AS OF 1 MAY
BAR
(b) PROGRAM
PURCHASE PART
FABRICATE PART IN HOUSE
SUB-CONTRACT PART
SUB-ASSEMBLY "A"
SUB-ASSEMBLY "B"
FINAL ASSEMBLY
TEST
SHIP
Working days prior to shipment - 22 work days per month

Figure 12

the criteria for a point to be designated "key"? First, the point should represent a measurable progress toward completion of the item, and second it should be a potential hang-up or bottleneck for the process that can be isolated for management control. The program or lead time diagram shown in Figure 12 represents the points that one unit goes through from start to stop. The scale is usually in work days; therefore initial purchasing must begin 24 work days before end item delivery. All other things being equal, a 1 day slip here would slip the ship date by 1 day.

The third component is the progress chart. This chart shows the status at each of the control points. In our example, the numbers 1-12 along the horizontal axis refer to the checkpoints 1-12 on the program chart. The scale along the vertical axis is the number of units. The scale reflects units 0-80 because that is what the contract calls for--delivery of 80 units. So far we can see that 60 units have passed through check point 1, 45 through checkpoint 2, 49 through checkpoint 3,..., and 14 have been shipped.

And now we get to the line of balance itself. The line of balance is an actual line drawn on the progress chart. This line shows how many units should have pushed through a given point by a certain date. Examining the line of balance drawn in the example we note the differences between the line and the status shown by the vertical bars. These differences reflect situations ahead or behind schedule at the given points. For example, note that activity is ahead of schedule at points 1, 4, 6, and 9. Activity is behind schedule at all other points.

The line of balance itself is constructed from information on the objective, the program and the progress chart. The line is different for each point and is calculated as follows. For example, let's compute the line of balance at point 7. Say today is 1 May, how many inputs should be at point number 7? Since the lead time for this point is 12 work days (from the program), we should check how many units are required at "ship" on 16 May (12 workdays hence). Looking at the objective chart, we notice that the schedule calls for 41 units to be shipped on 16 May. Therefore, 12 days earlier, i.e., on 1 May, we need 41 units through checkpoint 7. Since there are only 19 units we conclude we have troubles.

Strengths and Weaknesses

The line of balance technique is a special application of networking so it shares most of the strong and weak points. However, this method is not as difficult to maintain as a full network would be for a large production effort. The tiering of many smaller networks is a much easier operation, especially for computer applications. It also condenses the presentation of current status to only flag significant problems. On the other hand, it will not isolate the part of an operation leading to a check point that is causing a behind schedule condition. The manager still has to ferret out that information.

Example

Figure 13 is an example of a contractor prepared line of balance report from the TIPI Program Office here at ESD. The program part of the chart has a maximum lead time of 18 months for each unit delivered. The contract calls for 18 units to be delivered by April of 1980, and each unit has 81 checkpoints or major milestones to complete. The line of balance at the "as of" date shows a combination of checkpoints ahead of and behind schedule.

A number of points are complete for all 18 units, while there are problems indicated at 8, 13, 16, 17, 18, 25, 30, 31, 32, 35, 36, 38, 40, 41, 42. In this case there was much dialogue between the SPO and the contractor on problem areas.

Chapter Five References

1. Techniques for Work Scheduling, Army Management Engineering Training Activity (AMETA), course handout, Rock Island Arsenal, Ill.

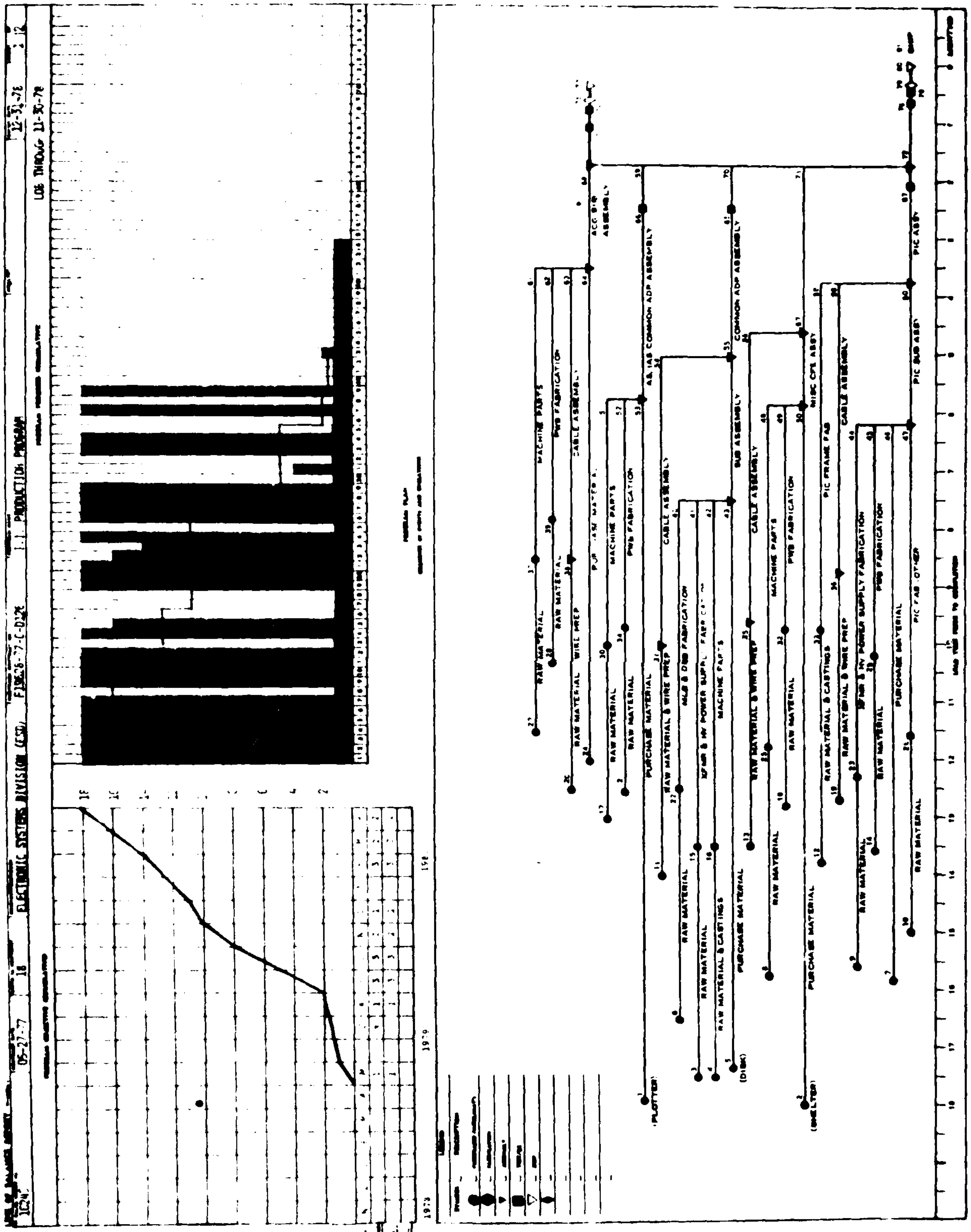

ELECTRONIC SYSTEMS DIVISION (ESD)
PRODUCTION PROGRAM
RAW MATERIAL
PURCHASE MATERIAL
MACHINE PARTS
PWB FABRICATION
CABLE ASSEMBLY
SUB ASSEMBLY
COMMON ADP ASSEMBLY
PIC SUB ASSY
PIC ASSY
(PLOTTER)
(DISK)
(SHELTER)

Figure 13

Chapter Six

MASTER INTEGRATED PROGRAM SCHEDULE

Introduction

In the previous chapters we have covered the major scheduling techniques that will be encountered within a Program Office. We have also focused on the need to schedule program activities in a way that clearly shows the dependencies or constraints between them while using a structure that allows us to track directly to the definition of the total job to be done (the Program Work Breakdown Structure) and the organizations responsible for getting it done. The experience here at ESD has shown that the most difficult part of the planning and scheduling process for a program is defining and relating the many tasks that the program office and other government people must accomplish. We are much more adept at laying out what our contractors must do. That is why we stress the term program as more inclusive than contract in the WBS and Master Schedule.

In this chapter we will present one very usable approach to developing a Master Integrated Program Schedule (MIPS) based on techniques that have been successful in one ESD program (SACDIN-ESD/DCV). This approach is based on a mechanism for networking coupled with a procedure for pulling together all of the expert information needed to construct it. The next chapter will show a practical way to maintain and report information from this network through a milestone schedule system.

Definition

The term "Master Integrated Schedule" is frequently found throughout weapon system acquisition literature. Adopting a definition from Major John Douglass (reference 1: "Development of an Integrated Master Schedule"), an MIPS is:

> ... a detailed program schedule which portrays all of the major elements of a program and all related development efforts in such a manner that the interrelationships are easily seen. The schedule is updated regularly and is recognized by all program personnel as the only schedule authorized for publication outside the program. The schedule is reviewed and validated at least monthly by the program manager.

Adding to that definition, the MIPS represents the Program Baseline Schedule. It is a schedule prepared by the program office to address the interrelations and interactions of all government and contractor organizations in the support of the program. It is not a contractor prepared data item.

Background

Although the term "Master Schedule" is frequently heard, a product which resembles the above definition has been lacking in many ESD SPOs. This conclusion is supported by past staff assistance visits. Based upon findings of the Hq AFSC Program Management Assistance Group (PMAG), the same situation exists throughout essentially all SPOs within AFSC. To date, most SPOs, have not developed (or have not been able to develop) a Master Integrated Program Schedule.

Instead of a MIPS the typical scheduling information within a SPO consists of:

a. A single viewgraph used for the Command Assessment Review or in-house briefing which depicts the overall program schedule. This is frequently referenced as the baseline or master integrated schedule but it only depicts 10 lines of top level schedule information.

b. Contractor data items. These come in all shapes and sizes. Some are good, but even the best generally only address the contractor's actions. They generally do not adequately cover the actions and interactions of the many other agencies (including the SPO) which are key to the total program schedule.

c. An assortment of schedules in the Program Management Plan (PMP), Test and Evaluation Master Plan (TEMP), Integrated Logistics Support Plan (ILSP), MOAs, and many other plans which are frequently inconsistent with each other and generally fail to cover all critical program actions.

None of the above available scheduling information items by themselves represents a MIPS. After numerous interviews throughout ESD, we believe that the reason for a lack of a MIPS within our SPOs is due to the lack of an easily usable and responsive technique for developing and maintaining it. Our people know how to plan their individual disciplines well. It is frequently the physical work which causes any inter-disciplinary planning effort to be abandoned or causes a desperate and normally unsuccessful turn to automation for help.

Anyone who has tried to build a network of any complexity recognizes the immense amount of work required to draw (and redraw and redraw) a network until an acceptable product is developed. When we consider that a MIPS for a major program can require 200-400 events, it is easy to see why most manual attempts have failed.

The failure of manual attempts has frequently made SPOs turn to either automation or to outside contractors (or both) for assistance in developing a MIPS. To date, results of their efforts have received mixed reviews. There has been no sustained use of any single automated scheduling networking technique at ESD. Automated efforts tend to produce large amounts of schedule data which can be useless unless someone can analyze the information. Obviously, the computer is no panacea.

Outside contractors are also not the complete solution. We frequently assume that our inability to develop a MIPS is due to a lack of internal talent and attempt to remedy this by outside expertise. Over-reliance on a contractor can also lead to problems since the information must still come from and be understood by the program office people.

Objectives

This approach builds on the study performed by Major Douglass (reference 1) which discusses the problems of developing a Master Schedule within a SPO and offers excellent, real-world advice based on numerous PMAG experiences and observations. The objective is to provide an effective and simple to use technique for developing a MIPS that:

a. Minimizes the need for extra training.

b. Distributes the schedule workload evenly throughout the SPO. This maximizes the involvement of all divisions and their functional disciplines in the MIPS development process.

c. Emphasizes the actions and interactions of all government and contractor organizations.

d. Supports numerous "what if" exercises and allows for easy assessment of schedule impact based on budget changes.

e. Supports internal workload planning, recognizing that staff and program resources have limited flexibility and that workload planning is essential.

f. Develops "the" master integrated schedule. The MIPS serves as the baseline for the planning of many organizations. A single recognized MIPS is essential for the efficient and integrated planning of effort by these organizations.

g. Enhances communications on schedule issues and which can serve as a diagnostic aid to schedule problems.

h. Can identify schedule problems early and can reduce the drain on SPO resources created by "fire fighting."

FLEXIBLE NETWORKING

Definition

The flexible network is a tool for providing the entire SPO with a visible and easily understood picture of the total program schedule. It consists of a network of events posted on a large wall surface or on boards

affixed to walls. The events are connected to depict interdependencies. Key to the success of the flexible network is the ease of preparing and more importantly the ease of changing the network.

Procedures

To develop a flexible network requires certain materials:

a. A room in which you can post a network on the wall. The network size should be 16 ft long by 4 ft high. A longer area is desirable and the technique will work with only an 8 ft surface. An easily accessible conference room is ideal.

b. The wall surface should be covered with a cork type surface. Homeosote boards (4' x 8') with a gray surface can be obtained from base supply channels. However, a cork surface obtained through local purchase makes a better looking display. Mounting the boards is a great self-help project.

c. Small (2½ in. by 1¾ in.) colored cards are used to identify each event. Different colors are used to indicate that the event is the responsibility of a particular agency (SPO, contractor, AFTEC, AFCC, etc.).

d. Map tacks (the type with the spherical head) are used to post the event cards to the cork board.

e. Black elastic thread, available at your friendly sewing supply store, is used to connect the events. The elastic thread is tied from one tack to another to depict interdependencies.

The above materials take a bit of effort to assemble, but the labor they save in the long run is many times the original effort to get started.

With materials in hand, you are ready to start developing a network.

Step 1. Form an MIPS team within the SPO. Business Management representation on the team is essential since that division will have the ultimate responsibility for maintenance of the network. However, the team should be chaired by the most qualified "planner" within the team. The ideal chairman is someone who has been assigned to the SPO for at least two years and who has a solid working knowledge of the total program. He or she may come from any division, but the knowledge ideally would be in more than one functional area.

The team is filled by four or five other people from other functional divisions. The best candidates are not necessarily the most experienced ones. Instead, aggressive and imaginative people should be chosen.

This MIPS project is an opportunity for providing some of the SPO entry level people with a good insight into the other SPO disciplines; an insight that local training course: cannot reproduce. The team will be required on a full time basis for the first two weeks and on a half-time basis for the following two weeks. This is a significant amount of work; however, the alternative is to continue expending all SPO resources without a definite plan. The team should be formally chartered by the System Program Director (SPD) with a license to ask questions and require responses.

Step 2. Review other MIPS efforts. Contact another SPO that has conducted the same exercise and make an appointment to view their flexible network. At this time, networks are available at the SACDIN SPO and at the E-3A SPO Business Managment Divisions. Seeing an actual network makes it easier to bring the team up to speed and is a good investment of an hour or two.

Step 3. Determine the scope of the network. The network can be built for a single project within a basket SPO, for a single major program, or for a number of small related projects which have significant numbers of interdependencies. It is not applicable to building a network of projects which are unrelated except by their technology or their assignment to the same program office.

Step 4. Gather data. The initial set of data should be gathered from written sources. These include:

a. DCP, PMD, AFSC Form 56 and other program direction.

b. PMP, TEMP, ILSP, CRISP or any other SPO plan which exists. Draft plans are adequate for this purpose.

c. Contract(s) delivery schedule(s), this schedule is contained in Section H of the contract.

d. Contractor action schedule. This is a data item available within Business Managment and in most divisions. Some contractors deliver both schedules and networks. Both are useful sources of data.

e. Contract GFE schedule. This is usually an attachment to the contract. Ask your PCO for it.

f. Any other source of either schedule or planning information. Note that useful information is not limited to information that indicates both an event and a time. If a Test and Evaluation Master Plan (TEMP) indicates that Initial Operational Test and Evaluation (IOT&E) will be conducted and that a Logistics Supportability Plan will be written-but fails to say when, this is still useful information. It will support the obvious question, "We plan to do this, when and who plans to do it?" Memoranda of Agreement are also good sources of data. They frequently require significant actions such as the provision of test resources without any referenced schedule. The scheduling of these resources is a key element of the MIPS development.

Step 5. Develop initial network. Having assembled your materials, your team and your data, you are finally ready to start. Divide up the work surface into time periods. You may want to expand the scale for the first year to provide ample space. Use the map tacks and the black elastic thread to make vertical lines dividing the board. If you decide to change the time scale, you will only have to move the tacks.

Fill out the action cards like this:

Event Description	No. 32
Purchase Request (PR) package assembled for external coord.	
WBS Interface: 5.2.1.5	
OPR	Schedule Date
DCVX	6 Nov 80

Figure 14

The cards are large enough so that use of any uncommon acronyms can be avoided. The network is supposed to answer questions, not raise them. Use different colored cards to represent the SPO, the contractor, procurement, and any other agency that plays a major role in the program (e.g. AFCC or AFLC). Use a separate color to identify miscellaneous organizations. (An alphabetical code will also let you tie in to a Responsibility Assignment Matrix scheme, reference Chapter 3.)

Using the source data, select events which you consider significant. Do not waste time arguing over whether an event is significant. If you wind up with too many low level events, it is easy to remove them later. Many seemingly low level events tend to be critical path activities. Source coding of system spares is an example of a frequently ignored event which can significantly impact the program. A delay in source coding can delay the development of Support Equipment such as Automatic Test Equipment (ATE) which in turn can delay Initial Operational Tests. Make a point not to argue over what is a significant event until after the first week. What you should be constantly on the lookout for are events that constrain the start of activities.

Do not duplicate the contractor's action schedule in total. Select some key events where the government and contractor formally interface (e.g. providing GFE, accepting delivery, major design reviews, major testing, etc.). Do not necessarily select the contractor's internal milestones as events for the network (e.g. start software spec, submit Preliminary Design Review agenda, etc.). Remember that your objective is to develop a program (not contract) network. You need to highlight the non-contractor actions required since only the SPO can plan these actions.

key on the responsibilities of outside agencies. These are our major scheduling problems. It is the planning of the work of the numerous other agencies involved which is the primary objective of the MIPS network.

If you are not sure when to schedule an event, take a guess. When you are not sure who is the OPR, take another guess. If you are wrong, the OPR will be quick to identify it.

At first, the density of early events will be quite large. We often have little problem in identifying the fires which are due in the next few months. The expanded scale for the first year of the network should alleviate some of the overcrowding. However, if the network becomes overcrowded, don't be concerned. You can clean it up later. Don't be concerned with eye appeal. You are trying to make a master plan - you are not trying to make a display for visiting firemen.

Step 6. Identify interdependencies. Begin with the first event and consider what following event is dependent upon successful completion of that event. Tie the black elastic sting between the two events. You will quickly become adept at tying knots. At first, some events will seem to be totally independent from others. This usually indicates that other significant events are missing. Most program events are interrelated. The exceptions (e.g. Command Assessment Review, Program Financial Reviews, and Budget Submissions) are generally few. The functional areas also tend, at first, to be independent of other areas. This independence also indicates that some events are missing. Most functional areas do have significant interactions with other functional areas.

Continue the process of identifying interdependencies until you have tried to connect each event to at least one following event. Note that certain major events (e.g. PMD release) may be necessary prior to the start of numerous other events. Try to depict all of these interdependencies.

Step 7. Identify problem areas. Make small triangular "flags" out of red paper. Pin a flag to any event for which a problem exists. If you had to guess at the date or guess at the OPR, flag the event until the data is confirmed by the OPR. If your written source data provided two different dates for the same event (a common occurence), flag the event. If an event occurs too late to support a following event, flag it. If an event provides inadequate lead time for procurement or for other activities, flag it. All lines in the network are interpreted to flow forward. If a line flows backward due to incorrect planning, flag the line. Events which need further study to identify interdependencies also should be flagged. Try to identify as many potential schedule problems as possible. The intent of the network is to identify these problems so that they can be resolved.

Step 8. Conduct initial division level review. Schedule each Division Chief and two or three of his or her staff for a two or three hour review of the network. Schedule the divisions in series. Identify the conventions and explain all of the events to the Division Chief. Do not limit the review to one functional area.

Seek to verify the information for that OPR or any information upon which he or she can shed light. As soon as further information is provided, immediately move or correct the event if the change is small. If the change is major, make detailed notes to support making the corrections later. A major benefit of the flexible network should quickly become apparent. It is easy to make even major changes without redrawing the entire network. A small shift of an event can be made without even retying the elastic string.

Attempt to resolve the flags in that division's functional area. If you can't resolve the division's flags, make a suspense for solving the problem. Try to issue one day suspenses. Avoid suspenses in excess of one week. Many of the following events may be affected by the flagged event and early resolution is essential. This effort should be the number one priority within the SPO at this time.

After verifying your initial data, ask the Division Chief to identify events which should be added. Do not be surprised if little information is volunteered. Some people do not like to post their plans because they fear being evaluated against that plan, or for other reasons. Others will volunteer a host of data which may be significant in their area, but which may not be applicable to the MIPS network. Try to limit this data to those areas which will involve interactions between functional areas or between organizations. If an event only connects to events within that division, it is not a likely candidate for the network. It is, however, an excellent candidate for the Lower Level or Intermediate Schedules discussed in the next chapter.

After this set of questions, ask the Division Chief to identify any events which should be added for other divisons or organizations to support that functional area. This question usually leads to a significant outpouring of useful data. While people may hesitate to identify their plans, they are normally quick to identify the support they need from others. Remember that each Divison Chief will have his chance to identify this type of data. This methodology has proven very successful. While most divisons will quickly identify their need for contracting action, only the PCO will be quick to identify when a complete contract package (e.g. PR, CCB Directive, SOW, etc) must be provided to contracting for action. The PCO will also be quick to identify the SPO, contract pricing, JAG, contract writing, auditor and other support he requires to complete the contract action. The MIPS network is an ideal tool for procurement planning.

After the interview, post all of the new information and continue with the next interview. Interview all Division Chiefs. Interview the MITRE project leader. He or she frequently directs more resources than any other Division Chief and these inputs can be vital to the scheduling process. Include the PCO and your liaison officers in the interviews. Continue the interviews sequentially.

Step 8. Revise the network. After the first series of interviews, the network will look like a cluttered spider's web. Try to clarify the network

by eliminating events which you now know are not truly significant. Rearrange the lines to eliminate the clutter. Try to keep functional lines clear. These revisions can be initiated during the interview process when there are slack periods. Don't postpone these updates.

Step 10. Staff Review (without Program Director). Schedule a review of the entire network by all Division Chiefs without the SPD in attendance. Attempt to again verify data and to resolve flags. This is the last chance to provide data prior to the SPD review. Stress the fact that all flagged items will be briefed to the SPD who will in turn expect briefings on the Division Chief's efforts to remove the flags.

Step 11. Review the MIPS Network with the SPD. After the division level review, schedule a three hour review with the SPD. He may recommend major changes in the schedule. If he does, make the changes, and repeat steps 8 and 9 again. After you successfully review the network with the SPD and avoid major changes, you have established a baseline schedule. Take a break. Then get set for a regular series of reviews and updates.

Schedule Maintenance

Once the network schedule has been developed, tracking, controlling, and updating come into play. Schedule maintenance will continue throughout the program. It is a dynamic process that taps many sources for information.

Schedule accomplishment is measured by more than the passing of calendar dates. Accomplishment may be represented by milestone events accomplished, percentages of tasks completed, and by expenditure of resources. The most obvious measure is if the event has come and gone (e.g., the request for proposal is on the street, the contract has been awarded, the first article has been delivered). Accomplished events will be reported by various means including contractor reports, and scuttlebutt. One thing is certain: You will miss half of this information if you wait for it to come to you. You have to stay on top of it. Start developing your contacts early.

Another aspect you should be aware of is that "schedules ain't what they seem." People can tell you that an activity is 90% complete, but frequently this means only that 90% of the allowed time has passed. A better measure would be that 9 of 10 meaningful sub-milestones have been met. You will have to develop a feel for what is "meaningful."

Because schedule and cost go together, some schedule accomplishment is measured in terms of cost. In contractor cost/schedule reports, schedule variance may be quantified by comparisons for work performed (earned value) and work planned. If the performance is less than the planned, we have an unfavorable schedule variance measured in dollars. This is but one indicator of schedule performance. Whether this unfavorable sign is corroborated by other schedule data will remain unknown until you check the other data.

Having developed the schedule (and updated it as necessary) and having established a satisfactory maintenance system, the next stage is to crank in ways to predict schedule performance. Trends can be identified and progress can be forecasted at an extrapolated rate. Time series analysis and some parametric equations can be used to predict, but these must be tempered by risk assessment. It is a good idea to identify the key risk areas early in the program. For example, software schedules are always risky; contract award estimates are usually optimistic; and fabrication normally encounters a delay. You will need to know how much "cushion" you have in each area before the whole program has to slip. Keep in mind how far you have come, how far you have to go, and what pitfalls you might encounter. We will show methods for dealing with these questions in a quantitative way in Chapter 8.

Chapter Six References

1. Douglass, John Wade, Major, USAF, "Development of an Integrated Master Schedule for Weapons System Acquisition," Study Project Report for Defense Systems Management College Program Management Course, Class 77-1, Fort Belvoir, Virginia 22060, May 1977.

Chapter 7

INTERMEDIATE SCHEDULES

Introduction

After the Flexible Networking effort is completed, the second phase of a Master Integrated Program Schedule can be implemented. As we discussed in Chapter 3, milestone schedules can be produced as an output of a network schedule to address limited functional (oriented to the performing organization) or lower level WBS aspects of the program. We will use the term "intermediate schedules" to identify this type of output. For example, an intermediate schedule might depict the Technical Order (TO) process and identify when preliminary TOs would be available, when verification and validation is planned, and when the TO's would be printed. The intermediate schedule should be limited in general to 10-20 milestones for a particular facet of the program.

With the flexible network and the contractor's schedules, there may be some question as to the need for "still more schedules." However, the intermediate schedules are a necessary element of a MIPS. The flexible network usually will not addresses all the major program events. For example, while the network may depict when a key piece of GFE is required by the contractor, it may not depict when it will be ordered, who will order it, or when it will be shipped. These events are, however, critical and must be planned. This is the role of the intermediate schedule. Major events from the flexible network are selected and an *intermediate schedule* is developed which identifies how the network milestone will be met. But remember, the network is still the official baseline schedule and the single point to incorporate and distribute changes.

Schedule Elements

The intermediate schedules usually cover a functional area. a flow of logistics events leading to the delivery of TOs, a flow of configuration management events leading to Functional and Physical Configuration Audits (FCA/PCA), a flow of engineering events leading to the development of an external interface, or other similar functional flows are ideal candidates for intermediate schedules.

Outside Agencies. Intermediate schedules identify when a functional area requires support from another agency. The TO flow will identify a support requirement for printing by the Air Logistics Center. The FCA/PCA flow will indicate a requirement for manufacturing support. The engineering interface flow will indicate the need for an Interface Control Drawing with another agency. The intermediate schedule not only identifies the required outside agency support, it also identifies when that support is required. This permits the participating and supporting agencies to determine if the

required support can be made available to support the current plan. Intermediate schedules take the generalities that exist in MOA's and other agreements and convert them into specifics.

The intermediate schedule is an ideal way for insuring that outside support requirements are clearly identified. The major functional schedules can be made a standard part of the Program Management Plan (PMP) through the Responsibility Assignment Matrix approach from Chapter 3. The total book of intermediate schedules or only a select few can be made a reference in the appropriate MOA's. Organizations would then be committed to supporting a specific program schedule. If an organization has a problem with a change in the schedule at a later date, they have the chance to identify this problem during the update/coordination cycle of the intermediate schedules. The intermediate schedule offers a solid technique for communicating detailed schedule changes to supporting organizations so that they can change their support plans accordingly. A key benefit of this approach is the identification of additional interdependencies between network activities as outside support tasks become more clearly defined.

Individual Responsibility. The intermediate schedule is assigned to an individual within a functional area. The individual's name is listed on the schedule and provides an easy point of contact to outside agencies. Responsibility for planning and monitoring a particular facet of the program is assigned down to the level that the actual work is being accomplished. This has an added benefit of improving the use of MITRE resources. Many SPOs do not have sufficient visibility into their MITRE support staff which creates a barrier to effective communication and limits the effectiveness of the MITRE resources. By assigning specific schedules to individual MITRE engineers, this problem of communications is avoided. (The actual assignment is done by the MITRE project leader.)

Problem Tracking. The intermediate schedule also offers a method for insuring that fewer of our problems fall through the cracks. Frequently a problem is identified and there is no clear-cut means to insure that the problem is resolved and not forgotten. By using the intermediate schedule, a suspense can be issued to a SPO Division or external organization to add an intermediate schedule which specifically addresses and solves that problem.

Identification and Assignment. The selection of events or areas which require an intermediate schedule is an important process. Too many schedules will overload the SPO's limited resources. Too few will result in the expenditure of resources without adequate planning. The SPO needs to start out with a "reasonable" number of intermediate schedules and to gradually grow to a complete set of schedules. A "reasonable" number depends upon the nature of the program and upon the number of resources assigned to the program. One rule of thumb is to determine the total number of professionals assigned to the SPO. Include liaison officers, staff support (from AC, DE, PK, TOM, TOI) and any other resources either collocated or non-collocated. Include your MITRE support. It is reasonable to expect that every professional assigned to the SPO can produce and

maintain one or two intermediate schedules. In many SPO's, this calculation will produce more than 100 detailed intermediate schedules--an impressive data base to start with. (Note that workload inequalities may result in one person having more than the "average" number of schedules. This may require two actions. Business Management should examine whether critical areas of work were missed. If this is not the case, the SPD should review his assignment of resources to insure that resources and workload have been properly balanced.)

With the number of intermediate schedules in mind, review the flexible network. Determine which events are critical to the program and assign intermediate schedules to the OPRs. Determine which events require significant interactions between external agencies and assign an intermediate schedule. Determine those events which the "lessons learned" book indicates are problem areas and assign intermediate schedules. Try to distribute the workload to all of the divisions. Every division provides important and critical support to the program and every division should be assigned intermediate schedule responsibility.

Coordinate the draft list of intermediate schedules. Don't back down too soon. OPRs will identify a host of reasons why a certain area is not a problem area. OPRs will also claim that insufficient data exist to make an intermediate schedule. Assign the OPR a reasonable suspense and keep the schedule on the list. Quickly accept any additions. The divisions are the best source for identifying critical activities.

Have the divisions assign an individual OPR for each of their schedules during the coordination process. Try to push the level of responsibility to the lowest level to improve communications. Try to avoid assigning schedules to division chiefs, branch chiefs or group leaders. However, if a supervisor insists on keeping the responsibility at his level, don't argue. Let him run his shop his way.

Suspenses and Coordination. Assign a one month suspense for the first increment of schedules. Remember that developing an intermediate schedule does not simply require putting a plan on paper. It may require making the plan. Require the divisions to coordinate their schedules throughout the SPO during that month and prior to the submission to Business Management. This gives them a chance to iron out any of the bugs in a particular schedule.

After all of the schedules have been obtained, publish them as a draft book and circulate copies to the divisions for comment. Allow another month for the divisions to determine if there are conflicts between the schedules or if there are conflicts with the contractor's schedules. It is important during this period to insure that the SPO has gotten it all together.

The next step is to issue the revised book of schedules to all external agencies. Send one to everybody, especially those agencies that will provide

upport the SPO. Identify to all agencies that the book of intermediate schedules represents when their support is required and will become a required reference in all MOA's. This is your opportunity to find out if the external support can be made available when it is required. Allow the agencies another month for review and comment.

After comments are in, make the necessary revisions and issue the first official book of intermediate schedules. Have the book signed by the SPD. It now represents the official program office schedule and should become a part of the Program Management Plan by reference with key products included.

Schedule Updates and Baseline Tracking. All SPOs have a requirement for baseline schedule management. This means that some technique is required to identify and track changes to the program schedule in a similar fashion that changes to program costs are tracked. The intermediate schedules can provide this schedule management vehicle.

Every two or three months, have the OPRs update their intermediate schedules. The update cycle should be based on the extent of known changes and upon available resources. Assemble the book and coordinate it throughout the SPO. The coordination cycle for an update should be less than two weeks since the majority of the information will not have changed. After that cycle, send it to everybody once again. Again ask for comments, integrate the comments and publish the updated, signed book of schedules. The book will serve as an ideal track of all schedule changes and will serve the same function as the cost track data maintained within the SPO.

Automation. The above intermediate scheduling system can be implemented manually without automation. By distributing the workload, the average individual should have to prepare two milestone charts every three months - not an unreasonable workload. However, automation has been successfully applied to this technique by the AFSATCOM SPO and several others at ESD. The automated technique uses a mini-computer with a plotter to draw the schedules. The examples that follow (Figures 15 and 16) were drawn by the plotter. The benefits of automation are significant. The drudgery of making the milestone charts and updates is drastically reduced. The OPR simply feeds his marked-up schedule to a secretary who inputs the data into the computer. The output is a professional looking schedule. This allows the SPO to spend more time in planning and less time in drawing the plans.

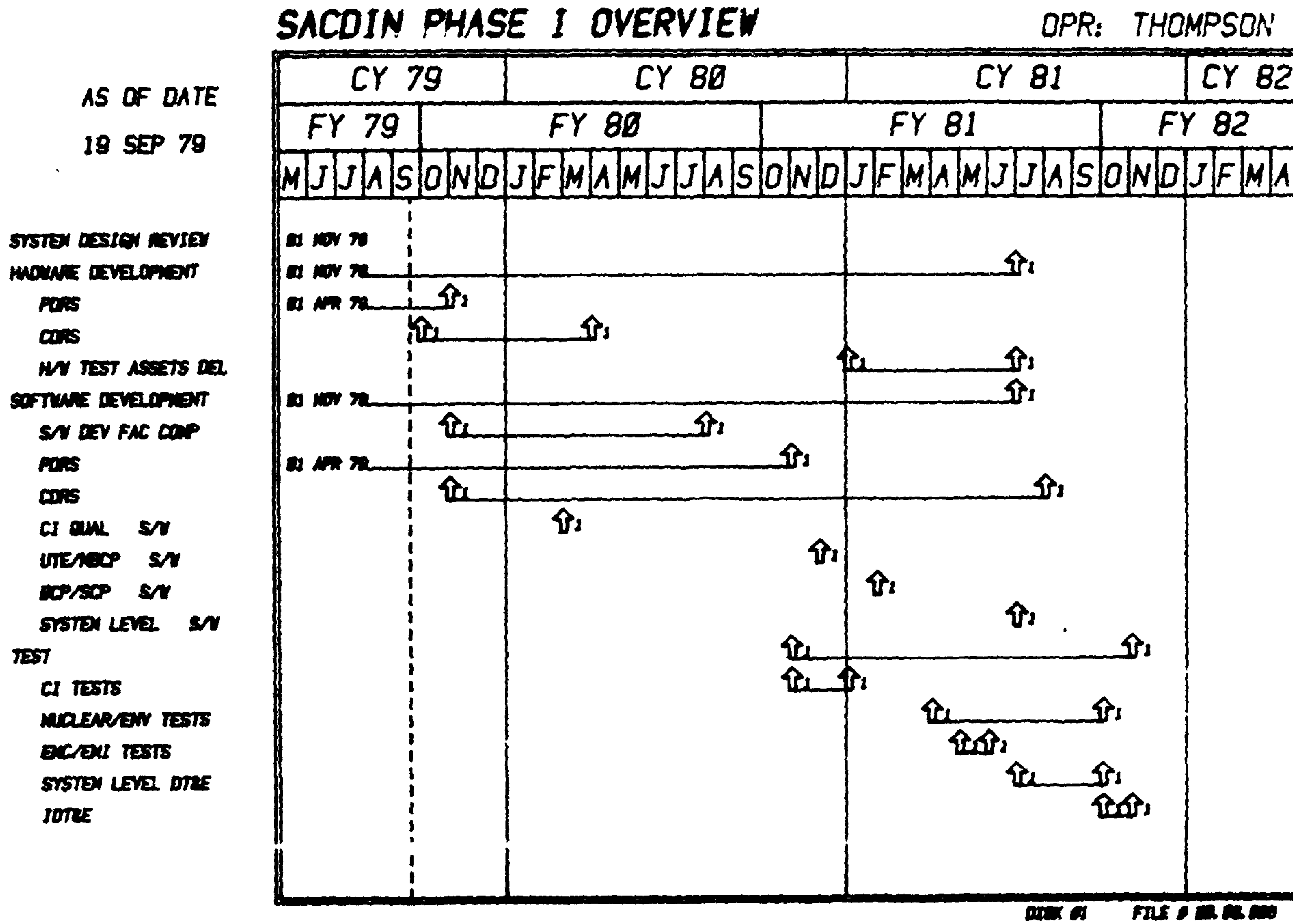
An additional set of benefits also comes with automation. Sorts of the schedule data base can be performed. The computer can identify all events which were supposed to be complete by a certain date. This generates a list of potential problem areas for review by the SPO. The computer can also generate a list of events scheduled for completion in the next 30/60/90 days to provide the divisions with an activity forecast. Other uses are also possible.

Getting the intermediate schedules automated, however, can consume considerable effort. Unless a system identical to existing systems is

procured, a SPO must expect to spend significant resources in developing a system. Buying computer hardware for this purpose is also a difficult process. Hiring a contractor to establish the system also is difficult and drains SPO resources in the management of another contract. While the long term benefits of automation will outweigh this drain, the major problem is that the fascination of automation may detract from the primary SPO objective - development of intermediate schedules. Note that the computer will not make the plans - it only will draw them. We recommend that automation be deferred until after the SPO has published its first book of intermediate schedules and worked the bugs out. Robert Townsend in his book of management cautions and anecdotes "Up the Organization" (reference 1) gives sound advice here. He suggests that if your current system of reports is not running smoothly, then putting it in the computer will only "speed up the mess." He also advises that a manual backup capability can come in very handy.

Chapter Seven References

1. Townsend, Robert, Up the Organization, Alfred A. Knoph, Inc., New York, 1970.


SACDIN PHASE I OVERVIEW
OPR: THOMPSON
AS OF DATE
19 SEP 79
CY 79
CY 80
CY 81
CY 82
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M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A
SYSTEM DESIGN REVIEW
HADWARE DEVELOPMENT
PDRS
CDRS
H/W TEST ASSETS DEL
SOFTWARE DEVELOPMENT
S/W DEV FAC COMP
PDRS
CDRS
CI QUAL S/W
UTE/MBCP S/W
BCP/SCP S/W
SYSTEM LEVEL S/W
TEST
CI TESTS
NUCLEAR/ENV TESTS
EMC/EMI TESTS
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DISK #1
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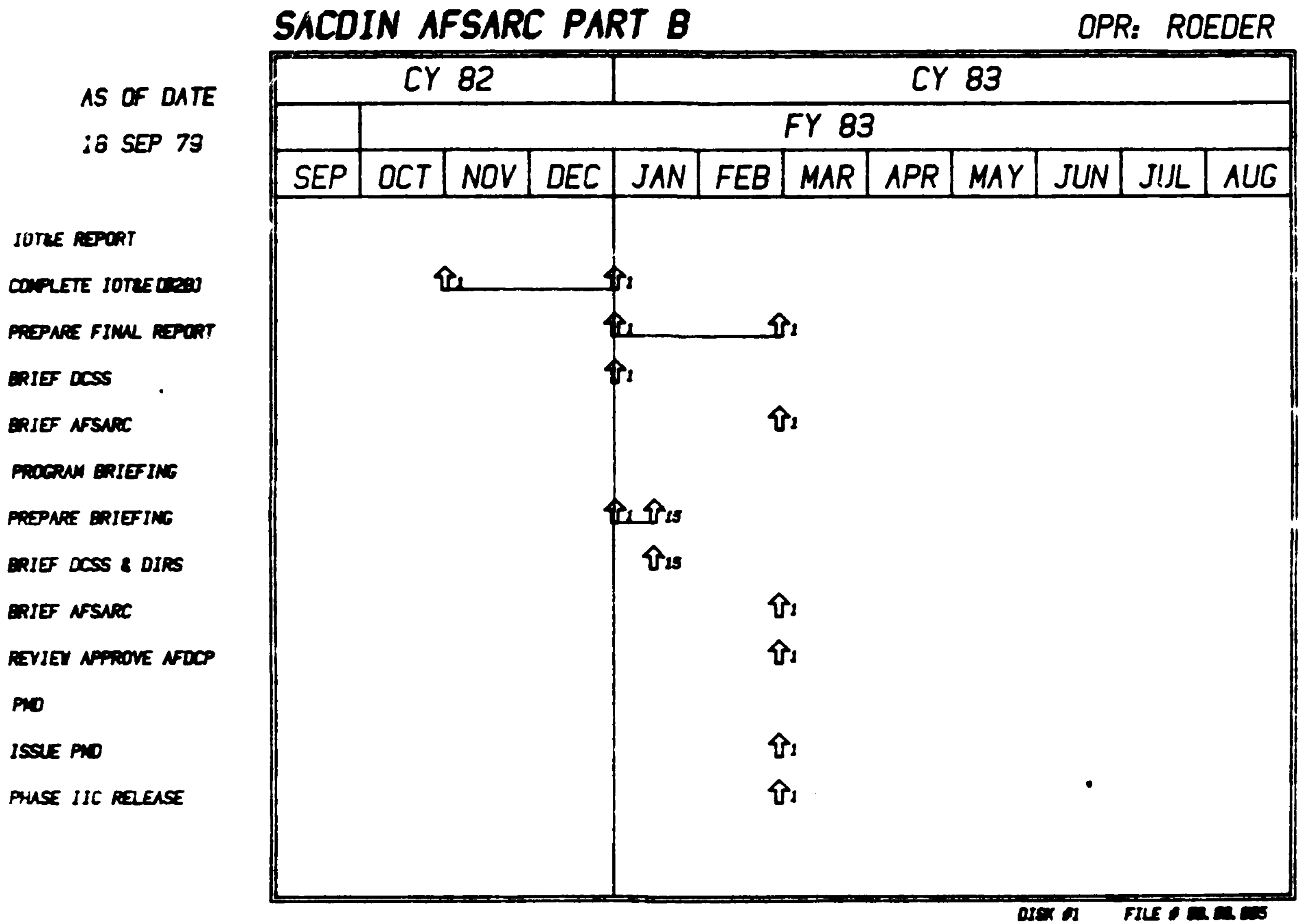
Figure 15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CY 82
CY 83
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SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
IOT&E REPORT
COMPLETE IOT&E
PREPARE FINAL REPORT
BRIEF DCSS
BRIEF AFSARC
PROGRAM BRIEFING
PREPARE BRIEFING
BRIEF DCSS & DIRS
BRIEF AFSARC
REVIEW APPROVE AFDCP
PMD
ISSUE PMD
PHASE IIC RELEASE
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Figure 16

Chapter Eight

COMPUTING UNCERTAINTY FOR A NETWORK

Introduction

Up to this point we have covered the basic scheduling techniques and layed out the approach and procedures for developing a Master Integrated Program Schedule complete with a flexible network and intermediate schedule. We have presented this material in a non quantitative manner so far; now we will address the more mathematical aspects in some detail. This chapter concentrates on the methods we can use to deal with the inevitable uncertainty surrounding schedules of program activities.

Analysis of uncertainty is not normally used as a management control technique or for the continuing effort of schedule maintenance, although it can be incorporated as a regular product of a computer-based system. What we will be principally aiming at here are the initial efforts during a planning stage as a network is constructed or one-time assessments or forecasts of program progress to support financial planning, etc. These techniques are also useful for an Independent Schedule Assessment, as defined by AFSCR 800-35, conducted along with an Independent Cost Analysis for key program decision points.

Basic PERT Probability

The primary assumptions used in developing the PERT statistical approach were:

1. The uncertainty of completing a schedule activity or task is best described by a Beta type of distribution for the probability of completion on a particular date or time interval. Figure 17 shows a Beta curve for a task measured in weeks from start. The cumulative probability of completion is the total area under the curve to any point.

2. The curve must be estimated without reference to any other network activities on the same path or elsewhere. Statistical independence is a key ingredient to the calculations used. Also, the curve does not take into account unusual influences such as accidents, strikes, acts of God, or any extraordinary efforts to compress the activity duration.

The Beta distribution was selected because it does not have to be symmetrical (can be skewed right or left), the mathematical behavior of the curve is well known, and there was no better alternative that suited the PERT developers.

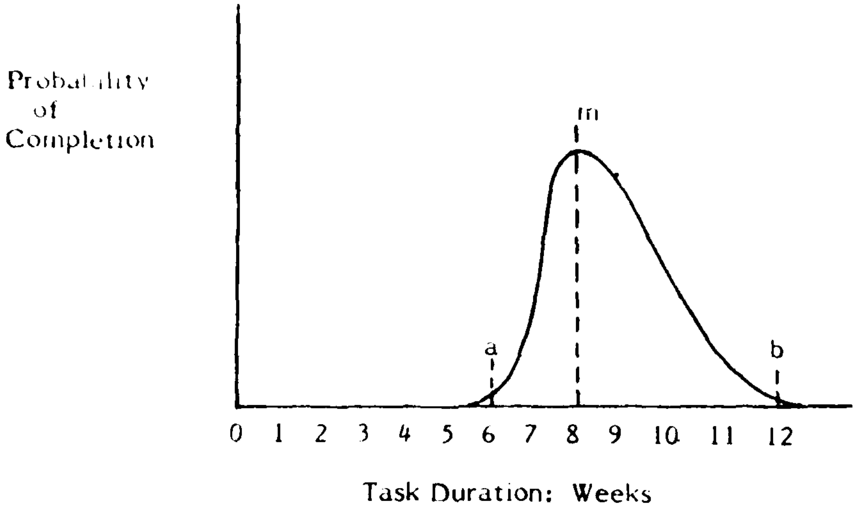


FIGURE 17

Without trying to get too deeply into statistical theory, there are a few basic characteristics of this type of curve that are used in PERT. The most optimistic time occurs at point a and represents a very small chance (about 1%) of happening. It should be arrived at by considering the shortest possible amount of time for a task, assuming that everything went well. Remember, at this point the objective is to pin down some of the "natural" characteristics of a task, and there is a length of time that could be achieved if each subtask was accomplished in the most time efficient way. (This is not "crashing," however; no extraordinary means for shortening the activity time, such as overtime, is assumed.) The fact that this time would rarely (if ever) be achieved agrees with the 1% probability of occurrence.

The next point on the curve is the most likely length of time shown at m or about 8 weeks. This is simply the high point on the curve, but it does not necessarily represent a cumulative 50% chance of completion by that date. In fact, it was the intuitive assumption that the most likely time was not equal to, and usually earlier than, the 50% point that led to the statistical treatment of 3 time estimates in PERT.

The final point that must be estimated to define the curve for an activity is the most pessimistic time b, or 12 weeks. This point represents about a 99% chance of completion or only a 1% chance of being exceeded. The assumption for estimating b is that everything required to complete the task takes the maximum time; everything goes wrong (aka Murphy's Law).

After estimating the two extreme times and the most likely time for the activity, the expected time, Te can be calculated by the simple formula:

$$Te = \frac{a+4m+b}{6}$$

The expected time should approximate a 50% chance of completion and thus is the most useful characteristic of an activity for laying out a program network. Although the formula is simple enough, the statistical theory that backs it up is fairly difficult to follow. Check reference 1, 2 or 3 for a detailed treatment.

The major difficulty with the PERT method is obtaining representative estimates for the two extremes, a and b, and the most pessimistic is more difficult of the two to get a handle on. The most likely time is much more readily available and probably is the basis for most milestone schedules already in existence for a program. We will present an alternative method later that can help eliminate some of this difficulty, but the overall strength and weakness of either method lies in the estimating process itself.

The use of multiple estimates for an activity allows us to construct a network that is much more representative of the real-world problems inherent in the program. It also lets us make use of mathematical statistics to characterize each activity and to calculate results at the total program level. These results can either quantify what we already felt was true or show that plans need to be changed to modify the schedule performance.

On the other hand, the basic accuracy (or inaccuracy) of the inputs cannot be improved by any form of calculation. The best we can do is structure the methods used to derive the inputs so the most confident information available can be ferreted out and applied to the network.

PERT and Risk Assessment

One of the most powerful aspects of the statistics used in PERT calculations is the approximation of the inherent spread or variance of completion times for an activity. For the Beta type of distribution the variance (σ^2) is given by the formula:

$$\sigma^2 = \frac{a-b}{6}^{2}$$

The standard deviation is simply the square root of the variance or one sixth of the range from the most optimistic to the most pessimistic time estimates.

The real benefit of this number comes as the statistical theory is again applied in two important steps:

1. The variances (σ^2) of sequential activities (such as along the network critical path) are additive to give a total variance for completing the entire path, or to any interim point along the path.

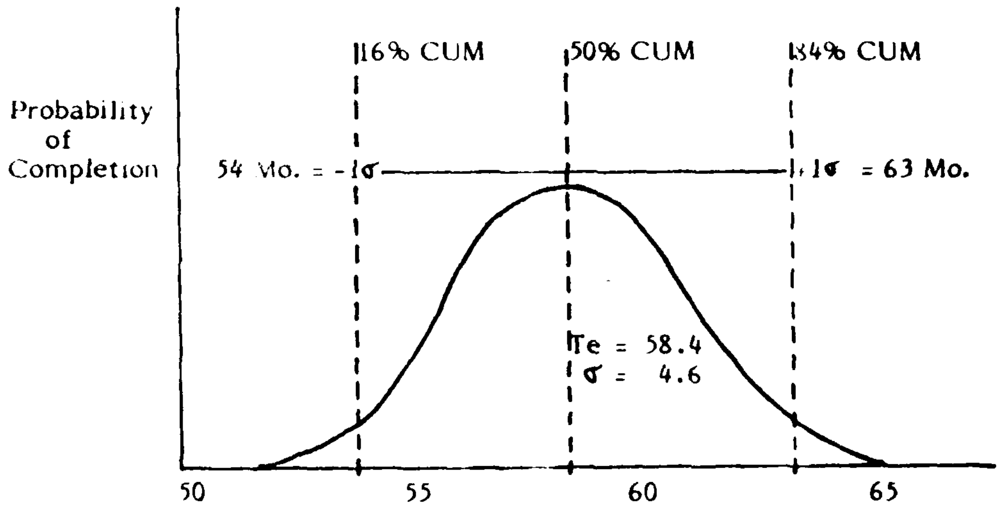
2. After about four or more activities are added, the total distribution of completion time for the project is approximately a normal (symmetrical or bell shaped) curve with a variance equal to the sum of the individual activity variances along the critical path of the network.

The second step allows us to take advantage of the well documented characteristics of the normal distribution by virtue of the most famous theorem in statistics: The Central Limit Theorem (for the mathematically curious see reference 2, page 200). This simply means that the possible completion times for each activity will add up to give a normal curve of probability for the duration of the entire project.

This greatly simplifies the calculations along any network path. All we need is the center point of the final curve and the total variance. The center point is the expected time for the path which is the sum of the individual activity expected times, Te (50% cumulative probability). The total variance is the sum of all activity variances on the path, and the square root of this total gives the standard deviation of the normal curve.

For the critical path of a hypothetical program with 11 major activities on the critical path, the range of uncertainty in duration for completing the entire project is shown by Figure 18. The essential data are:

Expected Time, Te		= 58.4 months
Total Variance,	σ^2	= 21.5
Standard Deviation,	σ	= 4.64 months



Project Duration: Months
FIGURE 18

As just one example of what can occur in a program schedule, the addition of all of the most likely time estimates for this example gives 52 months, which is over 6 months less than the expected time, with only about a 10% chance of occurring. Moving up higher to reach an 84% total confidence of completion takes 63 months or 11 months longer than the total of most likely times.

There are many sources for tables of the normal distribution, but Table I below is a summary of some of the key points based on adding or subtracting fractional values of the standard deviation from the center point of the curve. The cumulative probability for any point is reached by totaling the area under the curve to that point.

Cum Probability of Completion	Variation from Te ($X\sigma$)		Cum Probability of Completion
1%	-2.32	+2.32	99%
5%	-1.64	+1.64	95%
10%	-1.28	+1.28	90%
16%	-1.00	+1.00	84%
20%	-0.84	+0.84	80%
30%	-0.52	+0.52	70%
40%	-0.25	+0.25	60%
50%	-0.00	+0.00	50%

Table I (Ref 2, p. 222)

Comments on PERT Probability

There are many sources of analyses on the usefullness, strengths, and pitfalls of the statistical approach used in PERT. Each of the references given for this chapter deal with the topic in much detail and should be examined for a good understanding. Reference 1 is particularly readable and complete (see Chapter 4 and Appendix C).

The heart of the method is the technique used for the basic time estimates for each task. The use of multiple point estimates is much more useful than any single time estimate because experience has shown time and again that the single estimate won't happen and is more often optimistic than not. (Statistically, the probability of single point occurrence is zero.) Even critics of PERT, CPM, and network techniques in general, agree that a range of estimates is the best approach; the argument comes from the math used to combine them.

Trying to estimate the hypothetical 1% and 99% confidence points on an assumed beta distribution is a pretty tricky business for an activity that will occur only once and has not been done quite the same way before, if ever. Using some other type of distribution has been suggested, but each has its own pitfalls.

One way around the problem with estimating the key points of a distribution is a method used in Operations Research or decision theory. In this method we estimate the probability of occurrence of certain events, or group of events, that will have the greatest effect on the duration of an activity. For instance, the time required to prepare and coordinate a Purchase Request package with all of the supporting documentation is heavily dependent on the number of problems that are identified during the various coordination cycles and must be corrected by revisions. We could estimate, based on some prior experience and correlating with other program efforts, that the whole job should take 6 months with normal problems (moderate recycling for revisions) and about a 70% probability that we will achieve this figure. The other alternatives are estimated at 5 months with minimum problems, but only a 10% chance, and 7 months with some major problems with business strategy, funding, etc., causing another month of rework on the package, but only about a 20% chance of happening. We assume that one of these 3 possibilities will occur (10+70+20 = 100%).

In the next section we will show that all of the statistical simplicity of the PERT technique is retained with this approach, and the basis for estimating is tied to alternatives within the range of expertise available to a program office. It also allows us to deal with another network problem more easily.

The other major drawback to a strict PERT or CPM analysis is that they both concentrate on the critical path only. This becomes a problem when there are a number of other paths through the network that have a mean or expected time close to the expected length of the critical path. The uncertainty of completion (variance) for these parallel paths interfere with the strict critical path results, and there can be a good possibility that one of these other paths may *exceed the critical path length.* The problem is usually compounded by interactions between the paths by either common activities or merging points.

This problem with PERT and CPM has been given a good deal of coverage in Operations Research and Management Science publications. Reference 4 gives a good idea of the order of magnitude of the optimistic bias errors involved if the single path treatment is used.

The example in the reference, a fairly complex program (1,100 activities) consisting of 11 identical parallel projects and 100 common activities, was found to be as high as 50% in error (worst case) by comparing a critical path calculation with a simulation involving the entire network. Even for less severe situations (3 parallel paths) the single path length had to be increased by 8 to 25%, depending on the average variance of the activities.

Although some useful techniques will be presented in the next section, full network simulation (a computer-based technique using many combinations of possible outcomes for all the activities) is the best approach if a program contains many multiple paths through the network that are close in expected length to the critical path length. The question to ask is: "How close is too close?" There is a rule of thumb answer.

Reference 2, p. 239 shows that if the difference between the mean or expected values of two parallel paths is greater than twice the larger of the two standard deviations, the error in using the critical path only will be less than a few percent. The rule simply states that the two distributions are not "interferring" with each other and any joint effect can be ignored.

In summary the PERT or CPM statistical approach does have some basic error sources and we have covered two of the major ones here:

1. the activity time estimating method, and

2. single path analysis of uncertainty.

Both of these can cause an optimistic bias in the expected completion time for a program. Reference 1, p. 463, outlined the results of a series of cases in which the single path analysis of uncertainty caused 10 to 30% error (optimistic). The possible error in the basic activity time estimates is difficult to pin down, but is potentially the largest consistent source of errors, and definitely the most important part of the whole process. This leads to our treatment here of a practical alternate method, which also allows us to deal with some of the other PERT error sources.

Network Analysis with Discrete Time Estimates

As described earlier, the approach is based on estimating several alternatives for an activity with each tied to the possibility of a discrete event, or group of events, occurring that will have the greatest effect on the time needed to complete the activity. The objectives of this method are to aid the estimator by relating the task duration to effects within our grasp of personal experience or resources and to still retain the simplicity of uncertainty calculations for the network. It even allows us to apply some full network statistical calculations, if the network is relatively simple or computer resources are available for simulation.

As described in the previous section, this approach associates a time estimate with the probability of occurrence for that particular task length. The sum of all of the discrete probabilities for the alternatives must equal 100%, since one must occur. This section will concentrate on the network calculations used with this method and what the results look like.

The notation used, for convenience, is shown in Figure 19 below. The activity 0-1 is estimated with three alternative durations: 6 months with a 50% probability: 6(.5); 8 months with a 30% probability: 8(.3); and 10 months with 20%: 10(.2).

6(.5)	Te = 7.4 months
8(.3)	σ^2 = 2.44
10(.2)	σ = 1.56 months

Figure 19

There are several ways to deal with this discrete type of statistical distribution, but we will use the simplest first (Reference 5, p. 91-95). To calculate the expected or mean time multiply each alternative length by the probability of occurrence and sum the products. In this case:

$$Te = 6 \times .50 + 8 \times .30 + 10 \times .20 = 7.4 \text{ months}$$

The variance (or spread) is given by squaring the difference between each time estimate and the mean, multiplying again by the associated probability, and adding the products, or:

$$\sigma^2 = (7.4-6)^2 \times .50 + (7.4-8)^2 \times .30 + (7.4-10)^2 \times .20 = 2.44$$

The standard deviation is the square root of this:

$$\sigma = \sqrt{2.44} = 1.56 \text{ months}$$

With these parameters we can proceed with the same single path probability calculations as shown with PERT. That is, the expected length of a path is the sum of the activity expected lengths and the total path variance is given by the sum of the activity variances. We can also apply the Central Limit Theorem for about four or more activities in series to give an approximately normal final distribution, as before, with the variance and mean known.

So the estimating process can be improved while still keeping the simplicity of calculation that PERT gives. But, for "trouble spots" in the network where the single path analysis is in error, we can use another approach to *deal with interferring parallel paths.*

In this case we assume two activities are constrained at the start and completion events, as shown in Figure 20, the expected times are close to the same length, and the standard deviation of the shorter path is large compared to the mean.

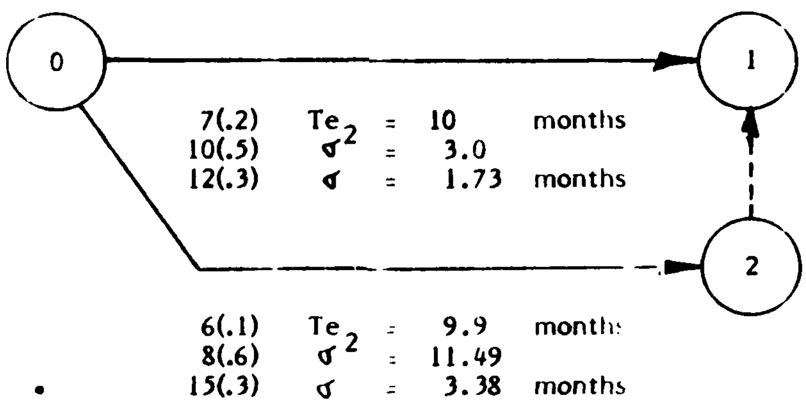


Figure 20

To calculate the effect of both activities together we must find the joint probability distribution and then calculate the expected time and variance from it.

The joint distribution defines all of the possible combinations of completion times for both activities along with the probability that any pair of times will occur together. The longest time of the pair is chosen for the joint probabilities because it is the one that constrains the distribution (both must be completed). In this case the probability of task 0-1 taking 10 months is 50% and that of task 0-2 for a 15 month duration is 30%. The probability of both of these alternatives occurring is the product of their individual probabilities or .50 x .30 = .15, or a 15% chance. But, if this happened, task 0-2 would constrain the total completion to a 15 month total, so we get a joint probability of 15 (.15).

The total distribution can be set up in a simple matrix shown in Table 2. For each intersection in the matrix, the probabilites are multiplied and the longest time of the pair is chosen. We then add all the probabilities for any given length that occurs in the product matrix to get the total distribution.

Parallel - Joint Probability Matrix

Task 0-1	Joint Distribution		
12(.3)	12(.03)	12(.18)	15(.09)
10(.5)	10(.05)	10(.30)	15(.15)
7(.2)	7(.02)	8(.12)	15(.06)
	6(.1)	8(.6)	15(.3)

Task 0-2

Table 2

Table 3 shows the resulting distribution and the new values of the expected time and the variance. The expected time is increased by 16% and the joint standard deviation is inbetween the two original values.

Joint Probability Results

Task Length (Probability)		Te	σ^2	
15 (.09 + .15 + .06)	(.30)	4.5	$(11.6-15)^2 \times .30$	= 3.47
12 (.03 + .18)	(.21)	2.52	$(11.6-12)^2 \times .21$	= .03
10 (.05 + .30)	(.35)	3.5	$(11.6-10)^2 \times .35$	= .90
8 (.12)	(.12)	.96	$(11.6-8)^2 \times .12$	= 1.56
7 (.02)	(.02)	.14	$(11.6-7)^2 \times .02$	= .42
TOTALS:	(1.00)	11.62		σ^2 = 6.38

Te = 11.6 months vs 10.0 from single path

σ^2 6.38

σ = 2.5 months vs 1.7 and 3.4

Table 3

This procedure can be used in simple cases throughout the network to take major interactions into account by condensing them into single equivalent activities. Large scale interactions, such as long parallel paths must be treated by some form of computer simulation. The matrix calculations get out of hand quickly!

The important thing to remember is that after you have identified areas of a program schedule that will cause errors in a critical path analysis, they must be dealt with somehow. Even a "seat of the pants" addition of 10 to 20% to account for the optimistic bias in the mean is better than nothing. But if you can deal with these areas quantitatively, the rule of thumb or management judgement can be left for issues that really don't have a better alternative. The schedule starts losing its value as a well disciplined communication device if we let "windage" calculations take over.

The discrete probability calculations can also be used to condense more complex areas in the schedule. This is done in steps to combine sequential activities and then the equivalent parallel elements. Figure 21 shows a typical problem area that cannot be treated with the critical path only, and it can be reduced to a single equivalent activity.

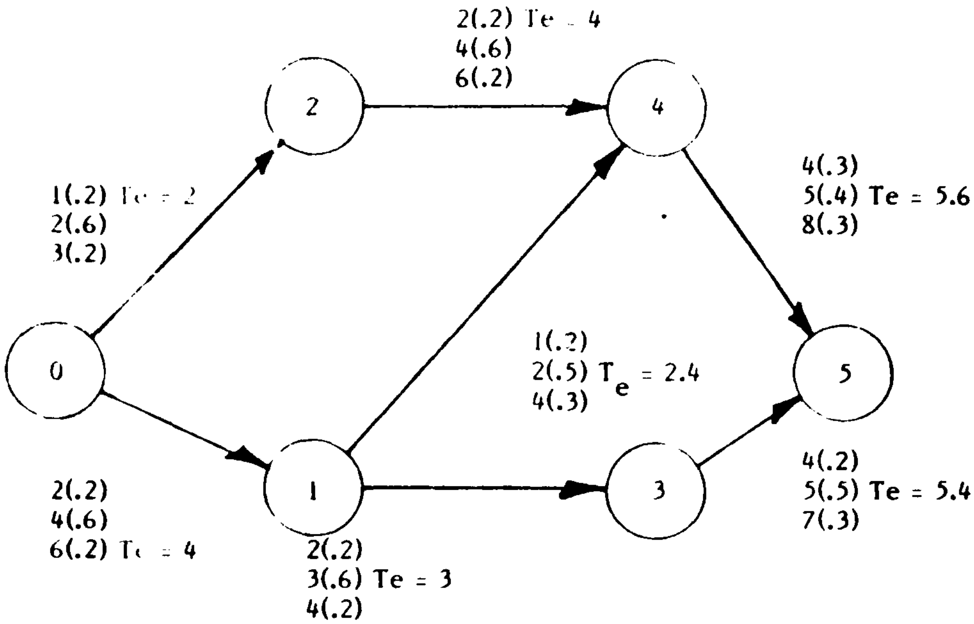


Figure 21

The critical path, 0-1-3-5, gives an expected duration of 12.4 months with a standard deviation of 1.8 months. Both of the other possible paths give total expected times less than one standard deviation from the critical path value: 0-2-4-5 = 11.6 months, and 0-1-4-5 = 12 months.

The first step is to combine the series activities 0-2 and 2-4 and the same with 0-1 and 1-4. This is done with another simple matrix of the same form as Table 2, except the activity durations are added for each joint pair since the two are occurring in sequence. Table 4 shows the matrix and results for combining activities 0-2 and 2-4.

Series - Joint Probability Matrix

Task 0-2	Joint Distribution		
1(.2)	3(.04)	5(.12)	7(.04)
2(.6)	4(.12)	6(.36)	8(.12)
3(.2)	5(.04)	7(.12)	9(.04)
	2(.2)	4(.6)	6(.2)
	Task 2-4		

Result: 0-2-4
3(.04)
4(.12)
5(.16)
6(.36)
7(.16)
8(.12)
9(.04)

TABLE 4

The same basic procedure is used to get the parallel joint probabilities for paths 0-2-4 in conjunction with path 0-1-4 (reference Table 2). Then activity 4-5 is added in a series matrix calculation giving a single distribution that accounts for path 0-2-4-5 and the effects of intersecting path 0-1-4.

The next step is to run the straight series calculations for the critical path 0-1-3-5. Again combining by matrix form and two at a time. First 0-1 is combined with 1-3 and that result with 3-5. (Note: the arithmetic is a lot easier if you round off sensibly and throw out insignificant points in the intermediate results, or program it in your calculator!)

The final matrix is a parallel combination of the two major path results, and in this case it contained 9 x 8 elements. The detailed calculations for this example were run in about an hour and a half with only a simple calculator. As discussed earlier, this example is an obvious case where single path treatment is not very accurate and the results bear that out. The critical path gives an expected time of 12.4 months while the matrix combinations give 14.4 months for the 50% confidence point. In this case the standard deviation was almost identical: 1.8 months single path versus 1.84 months for the whole network, but there is no intuitive way to find that out beforehand.

Full Network Simulation

If you are fortunate enough to have the access to computer resources with a networking capability, the best way to treat this type of problem is to make multiple runs of the entire network. In a Monte Carlo simulation the discrete probability estimates for the duration for each activity are coupled with random number generators. So, with each "run' one duration is randomly selected from the possibilities for every activity in the network, and then a critical path analysis is done giving the total project duration for that run and all the activities that were on the critical path. As the number of runs made increases, the times selected for each task by the Monte Carlo method begin to approach the discrete estimates. That is, for an estimate of 8 months and 60%, the number of times 8 months is selected will approach 60% of the total number of runs.

A full network simulation may give many different critical paths and one useful output is the number of times that a specific activity was on the critical path or its "criticality" to the program. Reference 6 shows a system that has been used on some Navy programs. It is based on full network simulation and gives outputs such as task criticality and a spectrum of earliest and latest start and complete dates for each activity. It will also accept various probability distributions, including the discrete type we have been using here.

What we have presented in this chapter are some techniques that can be used manually, but they are also adaptable to a range of automated treatments starting with programmable calculators to do the matrix arithmetic.

Relating Uncertainty and Risk

No matter which quantitative method is used our objective is to express the total effect of the individual elements of schedule uncertainty on program completion. The keys are to establish a clear set of ground rules for estimating schedule ranges for activities, identify interactions and interdependencies, and use a consistent and explicit method for combining these in total.

Although getting to this point may seem an insurmountable workload, a final schedule with completion dates expressed as a confidence range is only the first ingredient for risk assessment. Uncertainty calculations give us answers to questions like: "When will I have a 75% confidence of completion?" Risk assessment attempts to quantify the impact of a 25% chance of not completing by that same date.

We cannot make the point too strongly that schedule performance is intimately related to the cost and technical sides of program performance. Each side can only be separated as a one dimensional look at a 3-D problem. There are always impacts, and the trick is to tie the schedule range to the other two parameters in any way possible.

Summary

In this chapter we have covered some fairly straight-forward methods for dealing with schedule uncertainty in a quantitative fashion. We looked at the PERT probability treatment, some of its shortcomings, and presented several ways around PERT or CPM problem areas.

Statistical methods can be employed to quantify the collective wisdom of program participants about when tasks will be completed. The results can be used to define risks inherent in plans and budgets. The methods used should not add significantly to the normal errors in the basic estimating process, so improvements to the input data (i.e. by adding sources) should increase the overall accuracy.

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APPENDIX A

LIST OF ACRONYMS

AC - ESD Comptroller organization

ADPE - Automatic Data Processing Equipment

AFCC - Air Force Communications Command

AFLC - Air Force Logistics Command

AFSATCOM - Air Force Satellite Communications Program Office (ESD/DCK)

AFSC - Air Force Systems Command

AFSC Form 56 - AFSC Program Direction

AMETA - Army Management Engineering Training Activity

ATE - Automatic Test Equipment

BA - Budget Authorization

CA - Contract Award

CAR - Command Assessment Review

CCB - Configuration Control Board

CPC - Computer Program Component

CPCI - Computer Program Configuration Item

CPM - Critical Path Method

CPR - Cost Performance Report

CRISP - Computer Resources Integrated Support Plan

C/SCSC - Cost/Schedule Control Systems Criteria

DCP - Decision Coordination Paper

DE - ESD Civil Engineering organization

D&F - Determination and Findings

DSMC - Defense Systems Management College

DT&E - Development Test and Evaluation

EEC - Earliest Expected Completion time

ESD - Electronic Systems Division

FCA/PCA - Functional Configuration Audit/Physical Configuration Audit

GFE - Government Furnished Equipment

IG - Inspector General

ILS - Integrated Logistics Support

ILSP - Integrated Logistics Support Plan

IOC - Initial Operational Capability

IOT&E - Initial Operational Test and Evaluation

JAG - Judge Advocate General

LAC - Latest Allowable Completion time

MIPS - Master Integrated Program Schedule

MITRE - MIT Research Engineers Corp. - ESD's Systems Engineering support - a Federal Contract Research Center.

MOA - Memorandum of Agreement

OPR - Office of Primary Responsibility

PCO - Purchasing Contracting Officer

PERT - Program Evaluation and Review Technique

PK - ESD Contracts organization

PMAG - Program Management Assistance Group - HQ AFSC

PMD - Program Management Direction

PME - Prime Mission Equipment

PMP - Program Management Plan

PR - Purchase Request (AFSC/AFLC Form 36)

PWBS - Program Work Breakdown Structure

RFP - Request for Proposal

SACDIN - Strategic Air Command Digital Network Program Office (ESD/DCV)

SPD - System Program Director (also called SPO Director)

SPO - System Program Office (used same as Program Office here)

SOW - Statement of Work

TEMP - Test and Evaluation Master Plan

TIPI - Tactical Information Processing and Interpretation Program Office
(ESD/DCR-1)

TO - ESD Technical Operations organization

WBS - Work Breakdown Structure

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